

## **DEEPWATER PIPELINE MAINTENANCE AND REPAIR MANUAL**

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1. The first part of the document discusses the importance of maintaining accurate records of all transactions and activities. It emphasizes the need for transparency and accountability in financial reporting.

2. The second part of the document outlines the various methods and techniques used to collect and analyze data. It includes a detailed description of the experimental procedures and the statistical analysis performed.

3. The third part of the document presents the results of the study. It includes a series of tables and graphs that illustrate the findings of the research. The data shows a clear trend in the relationship between the variables studied.

4. The fourth part of the document discusses the implications of the findings. It highlights the potential applications of the research in various fields and the need for further investigation.

5. The fifth part of the document provides a conclusion and a summary of the key points. It reiterates the importance of the study and the need for continued research in this area.

6. The sixth part of the document includes a list of references and a bibliography. It cites the works of other researchers in the field and provides a comprehensive overview of the current state of knowledge.

7. The seventh part of the document contains a list of appendices and supplementary materials. These include additional data, figures, and tables that support the main text of the document.

8. The eighth part of the document includes a list of figures and tables. These are numbered and labeled to correspond to the text and provide a visual representation of the data.

9. The ninth part of the document contains a list of footnotes and endnotes. These provide additional information and references that are not included in the main text.

10. The tenth part of the document includes a list of acknowledgments and a thank you note. It expresses gratitude to the individuals and organizations that supported the research.

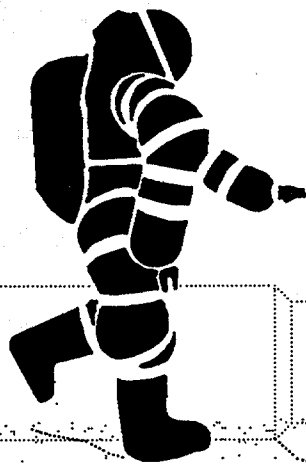
## **Chapter One**

### **INTRODUCTION**

# DEEPWATER PIPELINE MAINTENANCE AND REPAIR MANUAL

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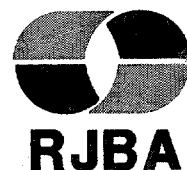
U.S. DEPARTMENT OF THE INTERIOR  
MINERALS MANAGEMENT SERVICE



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## Chapter One

### INTRODUCTION

The continuing development of offshore oil and gas resources has established the subsea pipeline as a reliable, cost effective and safe method of transportation of produced hydrocarbons. The need for subsea pipeline systems will continue as future oil and gas exploration results in discovery of hydrocarbon in more hostile areas and ever deeper waters.

The integrity of subsea pipeline systems, both during installation and throughout the operating life, is an important element for operators to improve reliability and service for economical, operational and environmental reasons. When pipeline damage from any source threatens production for any period, quick repair and return to service of the pipeline system is essential.

The first step, although outside the scope of this report, is for the subsea pipeline system to be designed and constructed to high standards as a survival offset to the many unknowns and constant hazards that are present in the offshore environment. Marine work takes longer with higher costs and requires more construction effort compared to similar work on land.

Also, pipeline operators must make careful choices between the three project factors of cost, quality and schedule which by definition are incompatible. Any two of the three can be achieved with varying compromises; however, the best quality costs more and usually takes longer.

Although not part of this report, various government authorities, depending on the location of the damage, must be notified immediately of any loss of pipeline integrity and leakage. These authorities may be involved in the repair steps and clean-up according to the law and applicable regulations.

The MINERALS MANAGEMENT SERVICE (MMS) of the U.S. Department of the Interior has sponsored this development and research project with the objectives of collecting information, organizing the knowledge and providing guidance for maintaining deepwater pipeline systems integrity during their operating life. Effective maintenance and repair of pipelines is another aspect of ensuring that subsea pipelines fulfill their operating purpose.

R.J. BROWN AND ASSOCIATES OF AMERICA, INC. (RJBA) has been selected by MMS to perform a detailed review of existing and developing maintenance and repair systems and guidelines on the relative costs, capabilities and limits of these systems. The guidelines are intended to cover repair systems for a wide range of pipeline diameters and conditions in water depth ranges of 1000 - 2500 feet and 3000 - 6000 feet.

This document presents the results of the work and is organized as follows:

- Chapter Two presents the Summary, Conclusions and Recommendations of the work both in the context of the manual and with respect to identified areas for further work to improve pipeline repair capabilities.
- Chapter Three gives the guidelines for performing a repair from the first information gathering stage through selection of a repair method, preparation and implementation. Subsections provide details of information needs, methods for record keeping and how the data sheets and matrices presented in the body of the manual should be interpreted.
- Chapter Four is concerned with the definition and categories of pipeline system damage. The chapter gives the various types of damage along with extent, possible causes and damage severity. Details are given in tabular matrix form for easy reference.
- Chapter Five has background information on "Modes of Intervention" in the performance of repair work. This section is included because a large number of repair systems are based on the limits of divers, ROV's and manned submersibles. Details of each system are shown in data sheet and tabular matrix form.
- Chapter Six covers how damage can be located, examined and assessed. Guidance is given on pipeline inspection and leak location techniques ranging from visual inspection to sophisticated, intelligent pigging systems. The chapter provides details of the forms of damage to be matched with each technique and their limits. Details are given in data sheet and tabular matrix form.
- Chapter Seven is concerned with minor repair and maintenance where the operation of the pipeline is not affected. These range from anode replacement and retrofit to span correction. The term 'minor' is a relative term for the manual because these marine operations involve major offshore activities and high costs. Again data sheets and tabular matrices are used for easy reference.

- Chapter Eight is the central part of the manual showing details of intermediate and major repair systems. Proven industry techniques are given as well as information on developing and prototype systems. In each case the systems are described along with their limits and special features. Data sheets, comparison matrices and diagrams are extensively used in this section.
- The Appendix contains an active list of suppliers of repair components and provides sources for vendors, fabricators, and contractors.



## **Chapter Two**

### **SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS**

## Chapter Two

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## Chapter Two

### SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

#### 2.1 SUMMARY

##### 2.1.1 Objective of Manual

Once commissioned, subsea pipelines must give continuous service with minimum interruption. However, submarine pipelines are in a hostile and largely unknown environment and exposed to hazards which may damage the pipeline and stop production. Fast, effective and economic repair of such damage is essential for minimum production loss. The purpose of this report is to establish the current state of capability of systems to make repairs on submarine pipelines because of damage, leaks or line breaks.

The information in this report is to provide guidance on the current day capabilities of pipeline maintenance and repair systems and on future developing repair systems to make timely and less expensive pipeline repairs in deep water. The objectives are:

- to provide a detailed view of existing, developing and conceptual repair systems in regards to key criteria, pipeline diameter and water depth; and
- to develop guidelines for each of the repair systems to establish their limits and to assist in the selection of the most effective system for a particular pipeline maintenance or repair situation.

##### 2.1.2 Structure of Manual

This report is described briefly in Chapter One. More detailed descriptions of the contents and organization of the manual are included in Chapter Three. This organization follows the steps of information gathering, background information review and repair option selection. These steps are shown in flow chart form with decision points and information entry and exit points. Defining information needs along with organized background information is one of the primary goals of this manual. The major information areas are:

- physical damage to the pipe wall;
- overstressing or fatigue damage;
- exterior damage or deterioration; and
- damage to pipeline system components such as valves, tees, and sections of flexible pipe.

Within each group the various forms of damage have been further described as:

- physical description of the damage;
- areas where damage can occur in the pipeline system;
- possible damage cause, subdivided into:
  - a) internal corrosion effects
  - b) external impact effects
  - c) environmental effects from severe storms
  - d) deficiencies in materials, design, fabrication or installation; and
- severity of damage and level of repair intervention required.

In this last subdivision, reference is made where appropriate to the means in which damage severity can be defined. This is especially relevant to less severe damage such as a gouge or dent where the requirement for a repair is not clearly defined.

Damage causes have been discussed in some detail to illustrate the range of potential sources. Also, certain forms of damage can be mitigated by correcting the cause rather than the effect. This aspect has also been addressed.

The damage categories in this manual provides six levels of damage severity which are:

- Level 1: superficial damage requiring very minor repair or monitoring;
- Level 2: damage that can be accommodated by derating the system;

- definition of the pipeline system characteristics, local conditions and nature of the damage;
- exact damage location and assessment techniques to be applied where the damage requires physical location or further monitoring;
- background details on damage types, severity level, damage cause and the intervention level for repair;
- the limits and capabilities of the selected means of human intervention at the repair site by use of divers, manned submersible or remotely operated vehicle; and
- required support equipment, hardware and procedures for the minor, intermediate and major repairs.

The information in these areas follows an established procedure. Details of each technique have been provided in text form with a description of the limits and technique applications relative to water depth. The details of the systems are shown in a summary data sheet format and in chart form for direct comparison. In these cases, the limits are listed for a consistent and defined set of key parameter headings which appear throughout the manual as follows:

- |                        |                      |
|------------------------|----------------------|
| • water depth          | • availability       |
| • pipeline diameter    | • development status |
| • mode of intervention | • experience         |

Illustrations of equipment and procedures have also been presented to support the descriptive text and summary sheets. All information is referenced for convenience.

### 2.1.3

#### Pipeline System Damage

The starting point in the process discussed above is the original indication that some form of pipeline system damage has occurred. The damage itself can take many forms with each form having different causes and severity. Because of the diversity of causes and effects, a section of the manual has been devoted to a description and a category of damage in a logical format, with the definition of suitable repair intervention measures for each damage category. In broad terms, damage has been segregated as:

- Level 3: damage, excluding the pipewall, requiring intervention without interruption of pipeline operation;
- Level 4: small leak or wall defect requiring repair without replacing sections of pipe;
- Level 5: medium-sized hole or split requiring major repair; and
- Level 6: full-bore rupture requiring pipeline shutdown and pipe section replacement.

Repair requirements have been assigned to each type and level of damage severity. The course of action following assessment of a particular damage situation can range from no intervention through pipeline shutdown and pipe section replacement.

#### **2.1.4 Mode of Intervention**

The majority of activities associated with the inspection of damage and subsequent repair involve some type of subsea intervention by divers, remotely operated vehicles (ROV's) or manned submersibles, where "intervention" is defined as a corrective or preventative action. The water depth is always an integral factor of any repair operation and will define the limits and practicality of the repair operation. Therefore, a section of the manual is concerned with the capabilities and limits of each intervention mode.

Most of repair operations to date have used diver intervention. The increasing trend to water depths greater than 1000 feet however, generated a need for increased diver working depths or replacement of divers by ROVs and submersibles.

#### **2.1.5 Damage Location and Assessment**

Although damage has been categorized into six levels of severity, a broader classification applies to damage location and assessment:

- Minor to Intermediate Damage of Severity Levels 1 through 4

The operation of the pipeline system may not be outwardly affected. This damage could go unnoticed for some time unless the pipeline is under scrutiny for other reasons or as part of an inspection program.

- Major Damage of Severity Levels 5 and 6

Substantial leakage from the system is involved so the damage should be detected as part of daily operations.

The emphasis in the manual has been directed towards the location and assessment of major damage. Techniques for the location of damage, inspection and information gathering at the damage site are given with regard to depth constraints. These techniques are also suitable for routine inspection purposes.

Damage location and assessment techniques have been grouped broadly into external and internal types.

The external group covers visual inspection by diver, ROV or submersible; acoustic systems operated from a surface vessel; surface towed fish or ROV/submersible mounted units; specialized methods for detection of the physical leakage itself; and cathodic protection monitoring systems. The limits and application for each system are explained for the kinds of damage found and inspected, water depth limits and damage location accuracy. The weaknesses of external pipeline inspection and damage location have been addressed.

The internal group covers devices which travel within the pipeline and detect leaks or defects in the pipe wall. These devices range from simple buckle detectors and gauging plates to complex instrumented or intelligent pigs. The limits of these systems are related to their specific capabilities to detect damage, not to external aspects such as water depth or mode of intervention. The range of defects that can be detected include:

- dents, gouges and wrinkles
- buckles
- leaks
- pitting and lamination type corrosion
- hard spots
- hydrogen blisters
- circumference cracks

A detailed review of the capabilities of internal pipeline monitoring devices has been prepared in both data sheet and matrix forms for easy reference.

### **2.1.6 Minor Intervention and Repair**

The term 'minor' repair, as defined in this manual, covers procedures done to correct deterioration in the pipeline system that do not significantly affect the operation of the pipeline. Although the term 'minor' is applied, it may not follow that the actual work is minor in scope. For example, rock dumping for span correction purposes falls into the minor repair category but the actual work is a major offshore effort.

The minor intervention and repair work in the manual cover the following main areas:

- subsea repair of concrete and corrosion coating;
- anode replacement or retrofit;
- span rectification;
- stabilization of pipelines; and
- scour prevention.

The available capability in each area has been documented with reference to practical water depth limits. In certain instances, ROV's with surface work vessel can be used in place of divers. An example is the placement of supports below a pipeline to correct spans. This has been done without divers on the Trans-Med pipeline which traverses waters up to 2000 feet.

### **2.1.7 Intermediate and Major Repair**

Most of the manual is devoted to intermediate and major repair activities which involve extended subsea operations on the pipeline system. This manual considers 'major' repair as the situation where a damaged pipe section is removed and replaced, with the pipeline system taken out of service. 'Intermediate' repair is defined by activities such as fitting welded

or bolted sleeves over the damaged pipe and does not necessarily mean that the pipeline is out of service. Since techniques for intermediate or major repair can use the same equipment, the information is shown under broad categories of repair systems, as discussed in the following sections.

#### 2.1.7.1

##### Established Construction Techniques and Equipment

In this category the emphasis is placed on techniques that have been developed and used in the industry for pipeline construction and repair. The primary techniques are:

- hyperbaric welding;
- repair during pipelay;
- surface lift; and
- flanged spoolpiece connection.
- hot tap and bypass.

This group covers virtually all established subsea repair systems. Each technique is described with a typical sequence of operations. Relevant hardware and equipment is also described and illustrated. The primary techniques are hyperbaric welding and surface lift; hence, a range of applications have been documented. The limits of each technique have been appraised and the mode of intervention plays an important role.

Hyperbaric welding, in its current operational form requires divers at the work site and is depth limited. Experience to about 700 feet is extensive and operational welds have been made in waters approaching 1000 feet. Below this depth, subsea welding is in the testing stage although research on improving diver working capability continues. Development on remotely operated welding systems also continues to help extend the depth capability by limiting diver use to simple set-up tasks.

Replacement of diver tasks with ROV's and/or manned submersibles is another direction for extending the working depth capability. Some of the repair techniques in this category would lend themselves to diver replacement once the alternative capability is proven. Areas where ROV or manned submersibles could play a greater role have been addressed in the manual.

### 2.1.7.2

#### Proprietary Hardware

This category covers repairs using specific types of mechanical connectors, cold forged connectors, and clamping devices available now. The details of the proprietary hardware are presented with individual suppliers. The systems provided by these organizations with associated repair procedures are described for each case.

The mechanical connector types available for pipe sizes to 48" diameter have been used often in water depths up to 1000 feet with diver support. Depending on type, the procedure involves work such as bolt tensioning and actuation which could be performed by an ROV. However, experience in this area is limited. Other mechanical connections require welding to prepared pipe ends. Their application is subject to hyperbaric welding limits unless the pipe ends can be brought to the surface for a dry weld.

Cold forged systems were developed as a answer to the subsea welding problem. Development of this type of coupling is progressing to improve the forging process and to allow ROV use of the forging tools. Experience with cold forging is limited beyond diver intervention depths.

Less severe damage can be repaired using sleeves or clamps which most currently require diver intervention. Experience to 1000 feet is extensive but limited for greater water depths. For deepwater, the procedures involved are slowly being adapted for ROV or manned submersibles use although limited experience exists in this area.

Subsea valves have also been addressed in the context of proprietary hardware although specific manufacturers have not been cited. Serious valve failure or damage in most cases require replacement of the valve and adjacent sections of pipe. However, some recently developed valve types can be serviced in place for certain forms of damage. These aspects have been considered in the guidelines.

### 2.1.7.3

#### Integrated Repair Systems

Several purpose designed integrated pipeline repair systems have been developed or are under development, primarily to meet the challenge of deepwater. These systems are being developed for diverless repair work in depths up to 8000 feet and well beyond any existing installed pipeline. The claimed capabilities indicate that damage repair up to pipe section replacement will be practical.

#### 2.1.7.4 Alternative Subsea Welding Techniques

Another area of development is alternative welding systems, notable automated welding systems for operation in a hyperbaric habitat. Robotic welding is well advanced for use in dry conditions for hyperbaric use. Most of the system are designed to that the set-up, welding, and NDT processes can be actuated by limited diver intervention or completely by ROV.

Wet welding and a number of advanced welding techniques have also been described. Most of these techniques have little chance of being applied for subsea use due to the equipment requirements and the need for a controlled environment.

#### 2.1.7.5 Emergency Repair Programs

One operating repair program has been identified and is described in the manual. This program is a joint venture where members contribute funds for an inventory of repair hardware, such as mechanical connectors, or the use of a rapid response vessel. The Response to Underwater Pipeline Emergencies (RUPE) has seventeen members and a repair hardware inventory positioned for the Gulf of Mexico area.

#### 2.1.7.6 Ancillary Repair Operations

Certain ancillary operations are required in support of a repair. These include: pipeline excavation, coating removal, pipeline preparation, pipeline dewatering and subsequent retesting and recommissioning. These subjects have been addressed in the manual.

### 2.2 **CONCLUSIONS**

This manual covers a wide range of aspects of deepwater submarine pipeline repair. Therefore, for ease of reference, the conclusions are grouped under the same subdivisions presented in the summary.

#### 2.2.1 **Pipeline System Damage**

A comprehensive damage categorization flowchart has been developed by this manual to identify possible sources of damage and assist in matching damage type and severity to the proper repair requirement.

Several agencies around the world have collected extensive data on submarine pipeline damage; however, this data requires condensing and processing to yield a useful database for damage categorization and risk prediction.

## **2.2.2 Modes of Intervention**

Intervention to 1000 feet water depth is normally achieved by saturation diving; therefore extensive experience exists for numerous repair operations. Industry considers 1000 feet to be the practical working limits for saturation diving with 1500 feet considered as operationally feasible but not practical at this time and there appears to be no significant research and development work on diver technology projected for the next few years, except an occasional experimental deep dive.

ROV and submersible capabilities to replace divers in repair tasks have improved greatly in recent years. Many ROVs are capable of operating at depths exceeding 6000 feet, a few can operate in up to 25,000 feet of water and most submersibles can operate in 2600 to 6600 feet water depth. This greatly extends the water depth to which pipeline maintenance and repairs can be made. In depths less than 1000 feet, ROVs can work with divers to extend their working limits. It is noted that currently there are very few pipelines on the continental shelf of the U.S. in water depths greater than 1000 feet and the proposed deepwater pipeline installations for the near future are in water depths less than 4000 feet.

As water depths increase, ROVs play an increasing role in the development of offshore oil reserves. To meet the demand, research and development attention will focus on refining existing robotic tool technology instead of vehicles technology, such as autonomy, since operational reliability of ROVs has reached a satisfactory level. The economic state of the offshore oil and gas industry has kept the day rates for ROVs relatively flat; therefore there are insufficient capital resources to improve and upgrade vehicle technology significantly.

## **2.2.3 Damage Location and Assessment**

Minor damage, such as dents, gouges and pinholes, which do not outwardly affect the operation of the pipeline are unlikely to be detected unless the system is on a routine inspection program or under surveillance for other reasons. However, major damage involving substantial leakage should be detected by day-to-day operations.

Damage may be located by external inspection or internal devices, but the process can be inaccurate and time consuming especially if the lines are buried. External inspection is usually performed visually by divers or submersibles. Internal inspection is increasingly turning to intelligent pigs

where provide more accurate and detailed information. However, it is still extremely difficult to correlate local anomalies on an internal pig log with the actual location in the pipeline. Most pigs are limited to a specific range of inspection services; therefore it may be necessary to run more than one pig if the type and extent of the damage is unclear or unknown.

It is to be noted that most Gulf of Mexico pipeline systems are not designed to be piggable with any pig other than a foam pig. The new deepwater systems being planned will need to address the requirement for or necessity of intelligent pigging. The need to design a deepwater pipeline system to be "smart" piggable can add significantly to the design complexity and costs of the system.

#### **2.2.4 Minor Intervention and Repair**

Most of the minor repair techniques are well established and have a long history of use with diver, ROV and surface support intervention. There is extensive experience with the use of ROVs alone for span connection and seafloor preparation. Those techniques not already utilized by ROV intervention lend themselves well to this application.

#### **2.2.5 Intermediate and Major Repair**

Intermediate and major repairs require extended subsea and sometimes surface intervention. The majority of these repairs involve the use of established techniques which usually incorporate a combination of hyperbaric welding, flanges and proprietary hardware. These operations are traditionally diver supported and therefore presently limited to diver accessible depths. Hyperbaric welding has a current practical working limit of approximately 1000 feet with 1500 feet considered as operationally feasible. Although there is one study currently underway to extend hyperbaric welding to 3000 feet, it does not appear that any advances will be made for the next several years. In some cases, retrieving the entire damaged line and installing a new pipeline may prove to be the most cost and environmentally sound repair method.

Cold forged connectors and robotic welding systems have been developed for use with a minimum of or no diver intervention and offer a good potential for deepwater use. Some of the mechanical connectors and split sleeve clamps have been adapted for ROV installation by special hydraulic tools. However, these devices are limited by the ROV payload and power capabilities.

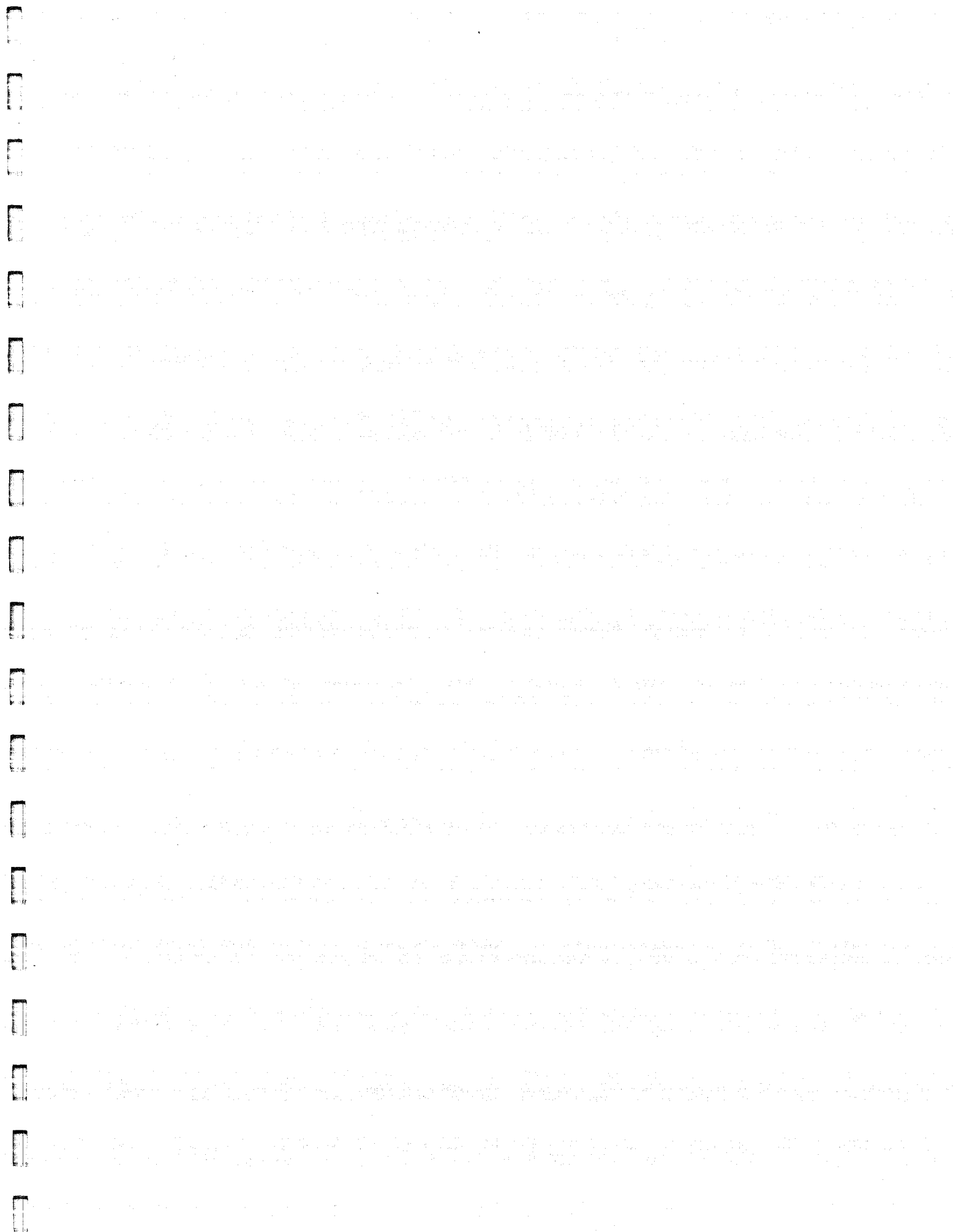
A few purpose designed integrated pipeline repair systems have been developed to perform all aspects of the damage repair from initial location and assessment to final inspection after the repair is complete. These systems are completely diverless and operational in up to 3000 feet. Generally speaking, repair technology, even these deepwater designed, multi-task, diverless systems, lag behind the offshore installation potential.

## 2.3

### RECOMMENDATIONS

The following activities are recommended to help improve the procedures and capabilities of pipeline system repairs.

- 1) Review existing codes and available research studies to define the criteria dictating the damage level and corresponding repair requirement.
- 2) Monitor/review the activities of organizations such as the Pipeline Research Committee of the American Gas Association to reduce duplication of effort.
- 3) Review/incorporate the ideas, procedures, etc. addressed at the recent Offshore Pipeline Safety conference.
- 4) Compile a set of guidelines for both routine and emergency inspection requirements since much of the existing technology with deepwater applications has limited usage experience and its availability may not be readily known in industry.
- 5) Develop industry guidelines or perform a joint industry study to evaluate recently developed technology and verify its integrity and specify areas where developments should be concentrated for mutual benefit.
- 6) Expand existing or create new emergency repair programs, such as RUPE, to include the new diverless technology and integrated repair systems.



### **Chapter Three**

## **INFORMATION REQUIREMENTS AND ORGANIZATION OF THE MANUAL**

## Chapter Three

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## Chapter Three

### INFORMATION REQUIREMENTS AND ORGANIZATION OF THE MANUAL

#### 3.1 INTRODUCTION

The manual is intended to provide the user with a better general understanding of subsea pipeline system repairs and enough basic information to select the maintenance or repair system that is best suited to the particular circumstances.

The manual has two primary levels of information:

- 1) The procedures involved in a pipeline repair from initial detection of a problem to completion of the repair work; and
- 2) Specific details of available and developing repair systems.

Although few pipeline repairs have been undertaken in water depths greater than 1000 feet, the volume of information about repair systems is substantial and the manual concentrates this wealth of detail in a concise and efficient manner. The following sections outline the contents of the manual and the method selected to convey the information.

The manual gives the capabilities of pipeline repair and support systems using key parameter headings with a summary of the main features of the pipeline system to be repaired. This method also allows systems to be compared without direct reference to a particular pipeline. These key parameter headings are shown in a following section.

The use of the manual for assistance in defining suitable repair scenarios for a particular pipeline relies on matching information about the pipeline system, local environment and the nature of the damage to the capabilities of the different repair and associated techniques. Details of information requirements are also presented in this Chapter.

Before listing repair system details, a general discussion is given of a pipeline repair situation from problem detection to repair completion. This discussion is presented in a logical manner whereby the information can be used as a practical guide for selecting a pipeline repair method.

## **3.2 PROCEDURE FOR PIPELINE SYSTEM REPAIR**

### **3.2.1 Repair Option Selection**

Each repair situation is different in terms of the location, operating conditions of the pipeline, nature and severity of damage, consequences of interruption in production, time of year, local available repair equipment and available information on which repair requirements can be determined. This list is not complete. Even with these differences, a general philosophy can be described for the repair of most subsea pipeline systems. The selection of repair options is shown in a control level flow chart in Figure 3.1. A flow chart is amenable to the later development of specific step by step procedures. Also the flow chart is useful as a firm basis for guidance in either written or computer based form.

The flow chart serves several purposes:

- shows the steps from when a problem is known to exist in the pipeline system through the selection of a short list of appropriate repair options;
- gives milestones where information about the pipeline system is required;
- tells where background information is accessed and evaluated; and
- identifies decision points.

The basic procedure illustrated in Figure 3.1 is shown in the following sections. Where the procedure involves the generation of an information file or reference to background information files, these points are noted. Further details on each block of information are given later in this section and in the main section of the manual.

### 3.2.1.1 Pipeline System Fault Detection

The start of the effort is the initial detection of a problem in the pipeline system. Detection of a fault can occur in several ways:

- abrupt changes in monitored or operating parameters such as sudden pressure loss;
- chance visual sighting of leakage or damage;
- observation or detection of leakage or damage during routine inspection activity;
- stuck pig or pig collection of unusual debris; and
- report of accident from external source such as notice of anchor contact.

Detection of possible damage or actual damage does not necessarily mean that the location or the nature of the damage is known.

### 3.2.1.2 Gather Available Information

The next step in the procedure involves data gathering to determine the location, nature and extent of damage as well as background information on the pipeline system and local environment. This data gathering process can involve several steps and draw on different sources. Typically, the information requirements would be broken down into three groups, as defined in Background Information File 1:

- information about the pipeline system;
- facts about the environment; and
- details of the damage itself.

In the first and second groups, information should be available from the original pipeline system design and as-built documents. Specific details of the damage itself may require investigation by appropriate damage location and monitoring methods.

### 3.2.1.3 Determine Damage Location and Assessment Measures

If specific damage has not been located or assessed, then some selected steps will be needed for the information gathering phase. Details of the

pipeline damage location and assessment techniques in Background Information File 2 are reviewed to select suitable methods for the pipeline system, water depth, locale, environment, etc.

3.2.1.4 Complete Project Data File

After measures are taken for gathering as much relevant data as possible, the final Project Data File can be prepared. This file provides the basis for the evaluation of damage severity and the required intervention measures.

3.2.1.5 Determine Severity of Damage

The severity of damage determines the intervention requirement for repair and the response time needed. Background Information File 3 provides a basis for determining the damage level.

3.2.1.6 Determine Course of Action

The subsequent action can be determined at this stage. A broad definition of repair requirement regarding the type of damage and the severity level is in Background Information File 3. The main courses of action are:

- no action - the damage does not merit any kind of intervention;
- system monitoring - the damage that does not require intervention except to check for further deterioration at specified intervals;
- system derating - the operating conditions are modified for the pipeline to satisfy code requirements;
- minor repair or maintenance - work is done on the outside of the pipeline without interruption of operations;
- intermediate repair - the operation of the pipeline system may be affected in some way; and
- major repair - the pipeline system is shut-down while repairs are made.

In all cases the records of the pipeline system are changed to reflect the action taken.

3.2.1.7 Determination Appropriate Intervention Technique

On the basis of the level of intervention required, the type of damage and specific pipeline and environmental conditions, the techniques for

intervention can be reviewed. Where system monitoring is required, details of inspection techniques are provided in Background Information File 2. For minor intervention or maintenance, details are given in Background Information File 4. Details pertaining to intermediate and major repair are provided in Background Information File 5.

### **3.2.2 Summary of Information Files**

The flow chart identifies five areas of background information and a project specific data file. The content of each of the Information Files is summarized below. Detailed information is given in the main body of the manual.

#### **3.2.2.1 Information Requirements (Information File 1)**

This file lists the requirements for data about the pipeline system, local environment and the nature of the damage to the pipeline system.

Section 3.3 provides details of the contents of this information requirements file and gives guidance on possible sources for the required data.

#### **3.2.2.2 Damage Location and Assessment (Information File 2)**

The collection of pipeline system information may identify deficiencies in the data. Typically, the location and extent of the damage is unknown. The second file provides information on suitable methods for inspecting the pipeline system along with location and assessment of the damage.

Chapter Six presents details of each inspection or leak location system in a consistent pattern following key parameter headings. These parameter headings are presented in further detail in a later section with examples. The format allows evaluation of the information regarding each technique/system, which can be compared directly with the specific project criteria to be met.

#### **3.2.2.3 Damage Categorization (Information File 3)**

The nature and severity of the damage must be evaluated before the selection of maintenance or repair measures can be made. This evaluation establishes the criticality of the damage and the nature of the intervention. Information File 3 gives the kinds of expected damage at different locations in a pipeline system, severity levels, possible causes and the choices of action. Chapter Four provides a general view of the intervention and helps with the maintenance/repair choices according to the type and severity of damage.

#### 3.2.2.4 Minor Intervention and Repair (Information File 4)

Where minor intervention or maintenance is selected as the course to follow, details are given for a group of key parameter headings. These parameter headings are arranged for ready comparison with the pipeline system, environment and damage details. Chapter Seven of the manual contains this information.

#### 3.2.2.5 Intermediate and Major Repair (Information File 5)

Most of the information in the manual is in the fifth file group. In this group, details of the repair equipment and operations are presented in defined format using a selected set of key parameter headings. The parameter headings are arranged for comparison with the pipeline system, environment and damage details with cross referencing as efficient as possible. The key set of the parameters is presented in further detail later in this section. Intermediate and major repair options are in Chapter Eight of the manual.

### 3.3 **INFORMATION REQUIREMENTS**

The list of information requirements to define a damage situation is divided into three groups:

- 1) pipeline system;
- 2) environment; and
- 3) damage.

The contents of each group are described in the following sections.

#### 3.3.1 **Pipeline System**

Information of the pipeline system as listed below should be available in the original design and as-built documents:

- outside diameter
- wall thickness
- pipe material and grade
- operating conditions
- pressure rating
- corrosion protection coating - type and thickness
- weight coating - make-up, density and thickness
- cathodic protection system

- product type
- trenching status
- route location

### 3.3.2 Environment

Information about the environment as listed below should be available in the base data for the original design, survey records and as-built data:

- geographical location
- water depth
- bathymetry
- operational wave conditions
- current conditions
- seabed conditions
- water temperatures

### 3.3.3 Damage

Information on the damage will be gathered on a case by case basis. The following details of the damage will be required:

- 1) Location: If unknown, a damage or leak location effort will be required as described in Chapter Six.
- 2) Type: In broad terms, there are four main groups of damage to a pipeline system:
  - physical damage to pipe wall
  - overstressing or fatigue damage
  - exterior damage or deterioration
  - damage to pipeline system components such as valves

The details of how these broad groups are subdivided are given in Chapter Four. Damage investigation methods are in Chapter Six.

- 3) Cause: In most cases the damage itself is the primary interest; however, some damage is 'repaired' by correcting the cause. An example is overstressing due to unsupported pipeline spans where correction of the span relieves the problem. Chapter Four gives damage causes related to possible severity.

- 4) Consequences: The need to initiate a repair is the consequence of the damage, the schedule time required for intervention and laws and regulations. Certain forms of damage may be left until a convenient time for repair as long as the integrity of the pipeline system can be assured. Other damage with high volume leaks will require immediate action. Consequences relates primarily to the damage severity although other factors such as high pipeline pressures with the properties of the transported hydrocarbons, nearby production platforms, marine traffic lanes and hazards to other facilities must be considered.

### 3.4 KEY PARAMETER HEADINGS

The various kinds of background information includes a consistent group of parameters which are used for convenient comparison of different repair systems. The group of parameters in this manual are as follows:

- Pipeline Diameter

The diameter of the pipeline can influence the type of repair and support procedure because some repair systems or components are not available for all sizes.

- Water Depth

The capabilities of almost all repair or associated systems relate to the depth of water because of human involvement. This may be directly with divers and manned submersibles, or indirectly and remotely with ROV's. Water depth influences other repair type operations such as the placing of rock from surface marine equipment.

- Mode of Intervention

Because of the importance of the mode of intervention and the relationship to water depth, a key parameter heading has been assigned to this aspect. The primary modes can be divided as follows:

- 1) diver
- 2) remotely operated vehicle
- 3) manned submersible
- 4) surface vessel
- 5) other

Chapter Five describes each intervention mode and its capabilities and limitations.

- **Availability**

This parameter describes the availability of the repair or associated system, mainly in terms of location. For example, certain specialist systems are only available in the North Sea.

- **Status of Development**

Most of the repair systems presented are fully developed and working with continuing improvements. However, some are in the design or prototype stages. This parameter explains the status as follows:

- 1) operational
- 2) prototype
- 3) conceptual

- **Experience**

The experience of each system is stated as follows:

- 1) extensive with possible water depth limits
- 2) limited
- 3) test only
- 4) none

### **3.5 DATA PRESENTATION**

The background information contained in the body of the manual is presented to comply with the defined group of information files given in Section 3.2.2.

Details are provided in text form for each repair or associated system. Diagrams are included as required.

The key information and other related data is shown in two ways:

- 1) Data Sheets which relay details of a specific repair or associated system; and
- 2) Comparison Matrices, which show information for a number of similar systems in a single diagram to allow easy comparison.

Details of each presentation format are presented on the following pages.

### 3.5.1

#### Data Sheets

There are several different forms of Data Sheets used in this manual. However, all have a similar format as shown in Figure 3.2. The features of the Data Sheets are as follows:

- Block 1 contains the reference numbering system which relates to the section number in the manual where the detailed text can be found. The third digit is the sequential Data Sheet number in that particular category.
- Block 2 presents the area and the category to which the Data Sheet is applicable. The area is the main division and includes:
  - 1) Mode of Intervention
  - 2) Damage Location and Assessment
  - 3) Subsea Pipeline Repair

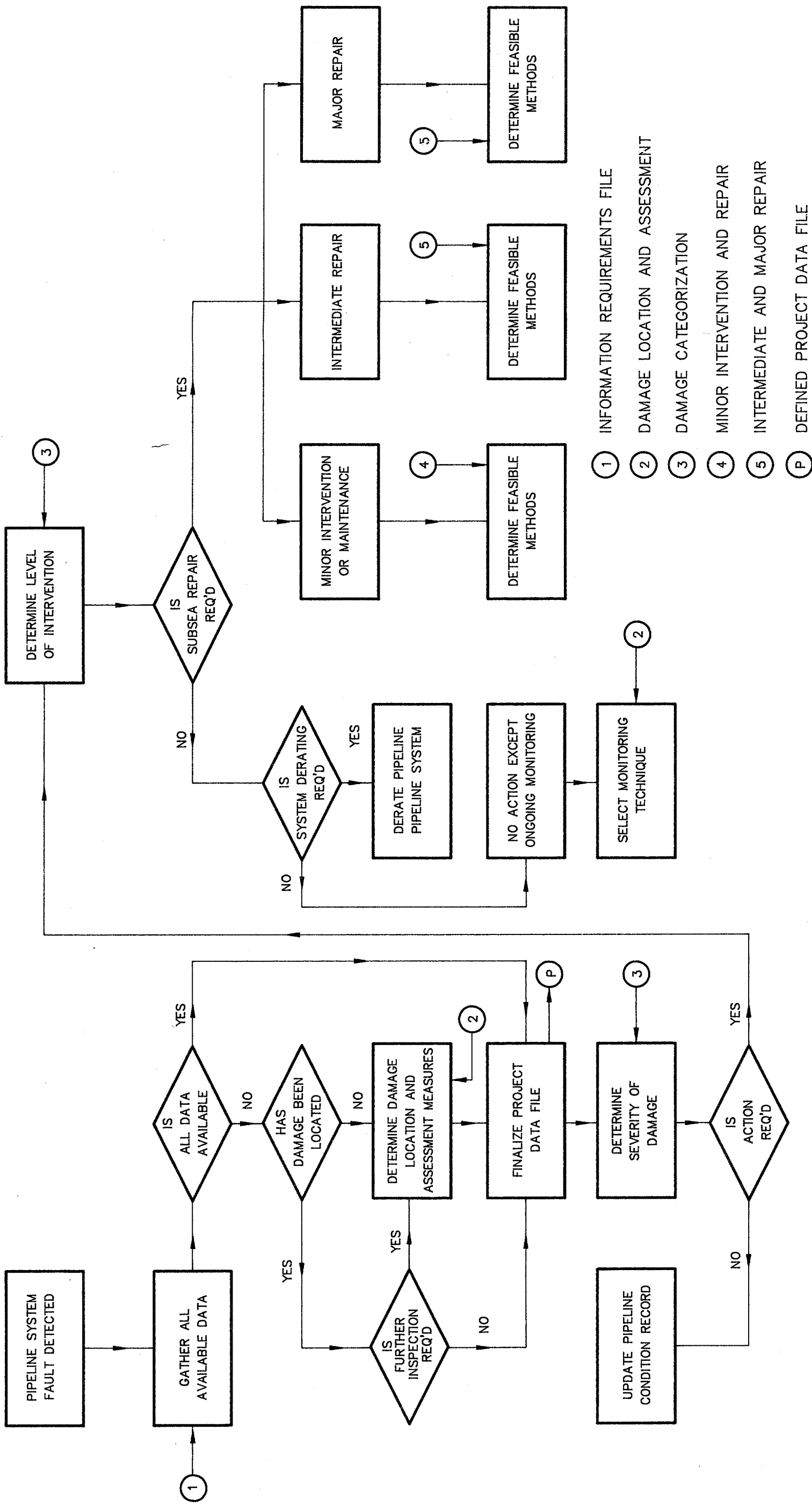
The category gives the subdivision of each area. For example, mode of intervention is divided into:

- 1) Diving Techniques
- 2) Remote Operated Vehicles
- 3) Manned submersibles
- 4) Multi-manned submersibles

- Block 3 identifies the subject technique, equipment system or procedure and provides a brief description. Depending on the Data Sheet, this block can also contain information on the function or application of system or procedure and supplier/operator detail.
- Block 4 lists the key parameter headings of the technique, equipment, system or procedure in the reference terms discussed in Section 3.4.
- Block 5 provides relevant additional information in a short form list. The additional information presented varies on a sheet by sheet basis.
- Block 5A presents a diagram or sketch where appropriate.
- Block 6 references the appropriate report section where detailed text can be found and where other relevant reference material is located.

### **3.5.2 Comparison Matrices**

The text and data sheets are summarized in a comparison matrix for each area. The repair methods are listed with the key parameter headings and other relevant information.



	<b>DEEPWATER PIPELINE MAINTENANCE AND REPAIR MANUAL</b>		<b>MINERALS MANAGEMENT SERVICE</b>				SCALE: 1=1	DOCUMENT NO: 66-3-11-001
	PROJECT		CLIENT		TITLE		JOB NO.: 2578.01	FIGURE NO. 3.1
	REV. 0	INITIAL RELEASE	BY BKR	DATE 8/30/91	CHK JRS	MLB	PROJ. ENGR. JGB	CAD FILE NO.: 2578-001.DWG

**BLOCK 2. AREA AND CATEGORY**

- AREAS: 1. MODE OF INTERVENTION  
2. DAMAGE LOCATION AND ASSESSMENT  
3. SUBSEA REPAIR SYSTEM

CATEGORIES: SUBDIVISIONS  
OF EACH AREA

**BLOCK 4. KEY FEATURES**

NOTE: LIST IS COMMON TO ALL  
DATA SHEETS AND PROVIDES A  
CONSISTENT REFERENCE PARAMETER  
SET FOR COMPARISON PURPOSES

**BLOCK 6. REFERENCE**

REFERS TO APPROPRIATE MANUAL  
SECTIONS FOR TECHNICAL DETAILS

DATA SHEET		REF. NO: X Y. Z.	
AREA:		CATEGORY:	
TECHNIQUE:			
DESCRIPTION:			
KEY PARAMETER:			
<ul style="list-style-type: none"><li>• PIPE DIAMETER:</li><li>• WATER DEPTH RANGE:</li><li>• MODE OF INTERVENTION:</li><li>• AVAILABILITY:</li><li>• DEVELOPMENT STATUS:</li><li>• EXPERIENCE:</li></ul>			
ADDITIONAL INFORMATION:			
REFERENCE:			

**BLOCK 1. REFERENCE NO.**

- X. CHAPTER NO.  
Y. SECTION NO.  
Z. DATA SHEET IN SEQUENCE

**BLOCK 3. SYSTEM DATA**


TECHNIQUE/SYSTEM/PROCEDURE OR  
EQUIPMENT  
  
DESCRIPTION/APPLICATION OR FUNCTION  
  
SUPPLIER/OPERATOR DETAILS

**BLOCK 5. ADDITIONAL INFORMATION**

PROVIDES FURTHER DETAILS UNDER  
SPECIFIC HEADINGS. HEADINGS LIST  
VARIES WITH EACH DATA SHEET SET

**BLOCK 5A. DIAGRAM**

PRESENTED WHERE APPROPRIATE

 <b>RJBA</b>	PROJECT	DEEPWATER PIPELINE MAINTENANCE AND REPAIR MANUAL					CLIENT	MINERALS MANAGEMENT SERVICE					SCALE:	1=1	DOCUMENT NO:	69-3-11-001
	REV.	0	INITIAL RELEASE	BKR	8/30/91	JRS	MLB	JGB	PROJ.	ENGR.	TITLE	JOB NO:		2578.01	FIGURE NO.	3.2
	DESCRIPTION	BY	DATE	CHK	ENGR.	ENGR.	CLIENT	DATA SHEET PRESENTATION		CAD FILE NO:		2578-002.DWG	CAD PLOT SCALE:		1=1	

## **Chapter Four**

### **PIPELINE SYSTEM DAMAGE**

## Chapter Four

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## Chapter Four

### PIPELINE SYSTEM DAMAGE

#### 4.1 DEFINITIONS AND TYPES OF DAMAGE

Damage to a pipeline system is defined as a change in the condition of the pipeline system which results in, or has the potential to result in, one or more of the following situations:

- the pipeline becomes a hazard, or potential hazard for the safety of personnel, property or environment;
- the safety of the pipeline system is threatened;
- the pipeline system does not meet fitness for service criteria in terms of regulatory or code requirements; or
- the capability of the pipeline system to perform its operating purpose is impaired or eliminated.

Damage can range from minor deterioration in the pipeline system to a full-scale rupture. It is important that the damage be classified as quickly as possible as:

- damage which involves no action other than monitoring for possible further deterioration;
- damage which can be tolerated by derating the pipeline system;
- damage requiring immediate response; or
- damage which must be repaired in the future.

Pipeline system deterioration can be the result of gradual damage to the integrity of the pipeline over a period of time or can be the result from accidental impact or extreme environmental conditions within a short time period.

The types of damage or deterioration are listed below:

1) Physical Damage to Pipe Wall

- internal corrosion
- external corrosion
- pinhole leak
- gouge, groove or notch
- puncture
- rupture
- cracking
- fracture
- buckle
- dent

2) Overstressing or Fatigue Damage

- severe bending without buckling
- fatigue damage
- over-pressure

3) Exterior Damage or Deterioration

- corrosion coating damage
- weight coating damage
- anode damage/loss/depletion.

4) Damage or Failure of Components

- valve damage, failure or leakage
- flange damage or leakage
- mechanical connector damage or leakage
- flexible pipe damage

The damage types listed are not necessarily independent. For example, a pinhole leak may be a result of corrosion or anode depletion from extensive damage of the corrosion coating. A further factor is that repair damage may not always be direct but may require correcting the cause. An example stated before is correction of spans to alleviate overstressing or ongoing fatigue damage. In view of the relationship between damage types, causes and repair requirements, the descriptions of the forms of pipeline system damage or deterioration set out in following sections refer to the level of damage severity in terms of:

- the part of the pipeline system affected;
- the source of the damage broadly grouped for
  - 1) internal effects
  - 2) external effects
  - 3) environmental effects
  - 4) deficiencies in design, fabrication or construction;
- code requirements;
- response requirements;
- requirement to shut down pipeline operations; and
- minor, intermediate or major repair intervention.

Each of these items are set out in matrix form in Table 4.1.

## 4.2

### PHYSICAL DAMAGE TO PIPE WALL

All of the damage types presented here appear as some physical change to the actual pipeline wall including the weld areas. Typical types of wall damage are illustrated in Figure 4.1.

#### 4.2.1

##### Internal Corrosion

Internal corrosion is a deterioration or destruction of the pipeline material through electro-chemical reaction with its environment. Some form of conductive electrolyte solution such as CO<sub>2</sub>, water, H<sub>2</sub>S, etc. must be present for corrosion to occur.

Generally, internal corrosion occurs because of the transport of corrosive materials mixed with hydrocarbons in association with the pipeline steel composition and inadequate measures to inhibit or guard against corrosion.

Examples of internal corrosion are:

- blanket or general
- pitting
- crevice
- stress cracking

These are just some of the forms of corrosion damage that can occur to the inside surfaces of a pipeline or one of its components.

Internal corrosion can affect all internal parts of the pipeline system and can be especially active at low spots such as the bottom of the pipe, bends, fittings and crevices. Damage severity ranges from minor deterioration in wall roughness quality to complete rupture. Levels of damage and associated response requirements are:

- Minor Pipe Wall Deterioration  
Minor corrosion damage which does not thin the wall enough to produce unacceptable hoop stresses, with regard to safety and code requirements, may not require repair. Efforts to inhibit further corrosion need to be made with regular monitoring of the corroded areas for possible worsening.
- Pipe Wall Thinning  
General corrosion of pitting that thins the wall to an extent resulting in unacceptable high hoop stresses may be left unattended in the short term if the working pressure of the pipeline is reduced to acceptable code levels. Corrosion inhibiting and monitoring measures may be taken.
- Advanced Corrosion and Pinhole Leaks  
At a more advanced stage of corrosion, wall thinning may reach unacceptable levels even with pressure reduction or may produce pinhole leaks in the wall. In this event, a rapid response will be required. Temporary repairs may be made to a leaking corroded pipeline by installing a full encirclement split sleeve or clamp. Complete shutdown of the pipeline may not be necessary.
- Pipeline Rupture  
Advanced corrosion can ultimately lead to a pipeline split or rupture. Immediate response is required to replace the affected section of pipe. Complete shutdown of the section of the pipeline system is required.

#### **4.2.2 External Corrosion**

External corrosion is also a deterioration or destruction of the pipeline material through electro-chemical reaction with its environment. Again, an electrolyte must be present. The corrosive agent in this event is the

seawater either under aerobic (oxygenated) or anaerobic (non-oxygenated) conditions.

The nature and extent of the corrosion depends on the prevalent conditions and the location. For example, corrosion attack under anaerobic conditions may occur for a section of buried pipeline. Corrosion in the presence of oxygen occurs in seawater and can be enhanced where an air interchange and mixing with the seawater is present.

A pipeline system design normally considers protection from external corrosion by means of paints, protective coatings and cathodic protection. Failures in any method of protection will generally result in corrosion. External corrosion is normally a slow process, except in highly oxygenated severe conditions such as a splash zone but with reasonable pipeline inspection and timely maintenance is unlikely to reach a critical stage.

Typical forms of corrosion damage are:

- general
- localized
- anaerobic

These corrosion forms are typical and represent the base mechanisms; but they do not cover all of the external corrosion damage that can occur.

The level of severity and required intervention measures are similar to those discussed for internal corrosion:

- Minor Pipe Wall Deterioration  
Indicates a potential problem which requires monitoring and measures to inhibit further corrosion.
- Pipe Wall Thinning  
Thinning to an extent unacceptable by pipeline safety and code constraints may be left uncorrected providing internal pressures are reduced to safe operating levels. Otherwise, a method to reinforce the wall is required in the near term.
- Advanced Corrosion and Pinhole Leaks  
At this stage, a rapid response is necessary to reinforce the pipe wall. Temporary repairs may be made using a split sleeve or clamp.

More permanent repairs involve a welded sleeve, patch, weld material fill or replacement of the affected pipe section.

- Pipeline Rupture

In this event, emergency response is necessary in the form of a temporary repair by sleeve or clamp, if possible, and replacement of the affected pipe section. The replacement option may be selected immediately, depending on the extent of damage. Pipeline shutdown is necessary.

#### **4.2.3 Pinhole Leak**

The pinhole leak has been discussed before as one possible result of corrosion damage. The pinhole is a small perforation in the pipe wall and is generally the result of corrosion pits, but can also occur from weld defects, material defects or external damage. A small pinhole leak may go undetected for some time since detection of minor pressure variation due to the leak is unlikely. A pinhole may occur under pipeline corrosion and weight coating making external location of the damage very difficult.

A pinhole leak is an unacceptable form of damage in terms of codes and safe operation and requires a rapid response to stop the leak and strengthen the pipe wall. Temporary repairs may be made using a split sleeve or clamp. More permanent repairs involve a welded sleeve, patch, weld material fill or replacement of the affected pipe section.

#### **4.2.2 Gouge, Groove or Notch**

Gouges, grooves and notches are sharp defects in the pipe wall caused by external impacts or loads.

The damage can be accompanied by localized denting and plastic deformation of the pipe wall. The depth, length, shape and extent of the local plastic deformation are all factors governing the chance for complete failure.

If cracking is present or the gouge is angular, then stress concentration occurs and failure, by fracture or otherwise, is more likely to follow. When a gouge, groove or notch penetrates the wall it becomes a puncture or rupture.

The damage can occur at any section of the pipeline exposed to sources of external impact or abrasion, although the likelihood of damage varies with location. Pipelines in the vicinity of offshore operations are at risk due to dropped objects, anchors, etc.

The severity of damage depends on the nature of the gouge, groove or notch. Different codes and standards worldwide set different allowable limits on the depth of damage. There are no universal rules on intervention requirements in relation to damage severity.

#### **4.2.5 Puncture**

A puncture is an externally caused physical penetration of the pipe characterized by an inward facing perforation of wall. The damage will be accompanied by localized denting. The shape and size of the puncture will depend on the type of object impacting the line and the nature of the impact.

The damage can occur at any section of the pipeline that can be exposed to sources of external impact, although the likelihood of damage varies with location.

By definition, a puncture constitutes a full penetration of the pipe wall and is a main source of leaks from the pipeline system. This situation is unacceptable from an operation and safety view and an immediate response is required. In most cases, the pipeline will be shut down and the damaged pipe section replaced.

#### **4.2.6 Rupture**

A rupture results from failure of the pipe wall and is typically an outward opening perforation. A rupture constitutes serious damage accompanied by a possible large leak of hydrocarbons. Damage of this type requires the pipeline to be shutdown and a repair made by replacement of the damaged section of pipe.

#### **4.2.7 Cracking**

Cracking occurs as a result of excessive bending of the pipeline. It is often associated with another sort of damage such as denting or buckling. A crack may propagate to form a fracture.

Cracking may also occur at a "hard spot" in the pipe due to stress corrosion or hydrogen stress cracking. Hard spots result from manufacturing defects or localized quenching of hot-rolled plates and are sections of the pipeline which are stiffer than the surrounding areas. The resultant flat area in pipe attracts considerable stress and in association with cathodic charging, hydrogen stress cracking can occur. Stress corrosion cracks invariably occur in clusters and often cover large areas of the pipe.

The damage can occur at any section of the pipeline system subject to stress corrosion or excessive bending.

The severity of cracking damage depends on the nature of the cracks. Clearly, the presence of cracks indicates that adverse conditions are present. Hence, cracking merits rapid response to arrest the damage before pipeline rupture or crack propagation (fracture) occurs.

The intervention requirements would include pressure reduction or full shutdown, with relieving the source of cracking and repair of damage by replacing the damaged section of pipe.

#### **4.2.8 Fracture**

When a flaw is present in the pipeline, such as a gouge or hard spots caused by mechanical damage, brittle or ductile fractures may initiate. A fracture is a propagation of a crack, normally along the longitudinal axis of the pipeline.

All fractures are severe and require emergency response by replacing of the damaged section of pipe and relieving the cause of the fracture.

#### **4.2.9 Buckle**

Buckling can take the form of local buckling, propagated buckling or bar buckling.

Local buckles are gross deformations of the pipe cross-section and occur because of a combination of bending, compression and external pressure, and impact loads. The presence of internal pressure will oppose the formation of local buckles. However, if the internal pressure is reduced to or below the ambient pressure, previously damaged sections may develop a local buckle or even propagate.

A propagating buckle starts as a local buckle and then travels along the pipe from external water pressure. In general, propagation buckles are the result of external pressure after a local buckle has started. These buckles can be stopped, but not prevented, by the use of buckle arrestors.

Bar buckling can occur as a result of internal pressure and temperature acting on an unsupported pipeline span. Under these compressive loads, the behavior of the span is similar to that of a buckling column with large lateral displacements and bending moments for small increases in load. If the unsupported pipeline span is in a trench, horizontal deflections are restricted by the side of the trench, but vertical deflection is possible.

Buckles can occur during construction to any section of the pipeline system. During operation, buckling may occur at sections of unsupported pipeline spans. Generally, buckling is unusual except during installation.

Buckling is severe damage which is unacceptable for pipeline operation since a rupture can result from the buckle. The damage requires rapid response and appropriate measures to replace the damaged section of pipe.

#### 4.2.10

#### Dent

A dent is defined as a depression which produces a gross disturbance in the curvature of the pipe wall. Dents can be caused by impact from anchors or dropped objects. Dents may lead to buckling of the pipeline or plastic failure at the dent, resulting in rupture.

Dents are classified as plain dents where the dent has smooth rounded contours or kinked dents which have hard edges.

In general, plain denting has little significance upon failure of pipelines under internal pressure. Dents of up to 24% of nominal diameter have been observed to flip out without permanent damage. Dents are relatively unstable and tend to revert to true circularity at relatively low pressures; however, significant cracking may form during the dent flip out, particularly under high internal pressures. This should also be taken into account when reviewing structural significance of plain dents in pipeline sections.

Dents also containing a defect, which act as stress concentrators, behave in a different manner than plain dents. The combination of a dent and a gouge considerably reduces the failure stress level. The reason for this

behavior is attributed to the instability of dents. As the dent reverts to the original pipe wall contour, rotation is induced around the defect region with subsequent defect extension and failure, particularly where cracks are concerned.

Dents may also prevent the passage of pigs.

The dent damage can occur at any section of the pipeline system that can be exposed to sources of external impact, although the likelihood of damage varies with location.

The severity of the damage depends on the depth and form of the dent. Different codes and standards worldwide set different tolerances on allowable dents.

The range of acceptance criteria for dents makes a clear definition of damage severity difficult. Each dent must be treated individually with consideration of all of the following factors:

- size and shape of dent;
- pipe diameter;
- properties of pipe material;
- contents;
- pressure;
- consequences of pipe rupture; and
- interference with pigging.

The severity of damage and required intervention therefore ranges from minimal severity with no repair necessary to serious denting the consequent removal/replacement of the damaged pipe section.

## **4.3 OVERSTRESSING OR FATIGUE DAMAGE**

### **4.3.1 Severe Bending Without Buckling**

This form of damage occurs when parts of the pipeline system are subject to severe bending because of its own weight, expansion or externally applied loads. The term 'damage' is not strictly correct since bending causes stresses beyond allowable limits, but within the elastic range of the pipe material. These bending stresses will not cause any permanent effect once the source of bending is removed. Bending which causes plastic

deformation will result in a permanent condition. However, this can be acceptable under some code constraints.

Excessive bending can occur in any section of the pipeline system that can be subject to the loadings noted above.

The degree of bending and consequent pipeline stress that can be accepted is related to the allowable operating stress limits within the appropriate pipeline code. This can vary depending on location of the bending and the stipulated condition of the code itself. Typically, bending acceptance is limited by the permissible combined stress (Von Mises Equivalent stress for example) to a level less than 0.72 Specified Minimum Yield Stress (SMYS) for functional loads only due to pressure, temperature, weight, etc. This can reduce to 0.5 SMYS in the vicinity of a platform. Where stress conditions are exceeded but no irreversible damage is done to the pipeline, intervention measures should be implemented to remove or rectify the bending problem. Emergency pipeline repair would only be required where cracks, excessive ovality or buckling are present or are likely to occur. The actual intervention measures depend on the nature of the problem.

Instability of the pipeline system requires correction by the provision of additional stabilization in the form of anchors, saddles, rock dumping or trenching.

Overstressing due to impact is usually accompanied by some other form of damage. Repair requirements would need to be assessed on a case by case basis.

#### 4.3.2

#### **Fatigue Damage**

Fatigue damage occurs when the pipe material and welds undergo an unacceptable number of cyclic variations in stress due to vibration or cyclic loading. A fatigue failure can occur after a cumulative build up even when peak stresses are within allowable stress limits. The failure usually takes the form of crack initiation, crack propagation and finally fracture. A fatigue crack in a welded joint develops from defects which usually are located in areas of stress concentration.

The cyclic loading which causes the fatigue damage is normally caused by current induced loading or vibrations due to response to vortex shedding from the external flow induced resonance.

Pipe vibration caused by internal flow effects has been experienced. Therefore, fatigue damage build-up may occur in any section of the pipeline system where the pipe is free to vibrate. Generally, this will include any sections of subsea unsupported pipeline spans. These same areas are also subject to both current loading and response to external flow induced vortex shedding.

A section of pipeline found to be vibrating may have suffered some cumulative fatigue deterioration without obvious signs of damage. In such cases, it is necessary to perform a fatigue/fracture mechanics analysis and possibly inspection of the pipe for signs of adverse cracking to determine the need for repair or to confirm the fitness of the pipeline system for service. At worst, fatigue damage will result in fractures which will involve emergency response and replacement of the damaged section of pipe. Hence, the level of severity and intervention requirements range from minor, with no action required, to pipe failure with full scale repair.

Fatigue analysis approaches are set out in a number of texts and some codes. These approaches are often explicit in that defined curves for threshold and acceptable levels of fatigue damage build up (in terms of stress range cycles) are given. These curves are based on tests. Fracture mechanics techniques are less well-defined and require a knowledge of initial defect sizes along with other data. The definition of the requirement to repair or to leave an affected section of pipe that have undergone fatigue damage must, therefore, be made on a case by case basis.

#### 4.3.3

#### Over-pressure

Overstress of the pipewall from internal pressure, in combination with other defects or damage, can ultimately lead to pipeline rupture. Over-pressure is therefore a cause rather than a type of damage. Pipeline rupture as a sole result of over-pressure is extremely unlikely due to the properties of the steel and in-built pressure limitations in the system (i.e. compressor or pump discharge pressure limits, pressure relief systems, etc.). Serious damage is more likely to occur as a result of a combination of over-pressure and other damage, such as corrosion, gouging, weld flaws, etc.

Overstressing due to over-pressure can occur throughout the pipeline system. Rupture due to over-pressure combined with existing damage can occur wherever this damage takes place. Since corrosion is one such source, then the rupture could occur at any point in the pipeline system.

For pipeline system over-pressuring, without resultant external damage, the outcome will be temporary overstressing of the pipeline. Depending on the excess pressure, this temporary situation may be acceptable and no intervention will be required except to correct the case of the over-pressure. Damage resulting from the over-pressure will require repair as discussed in the earlier sections pertaining to rupture fracture and pinhole leaks.

#### **4.4 EXTERNAL DAMAGE OR DETERIORATION**

##### **4.4.1 Corrosion Coating Damage**

Damage to corrosion coating can occur during pipeline installation or during operation. Damage encountered during transit for installation can also occur, but this should be repaired in accordance with applicable field repair specifications prior to the use of the pipe.

A common area for damage is during the passage of the pipeline between the installation vessel and the seabed. For example, corrosion coating can be damaged by bouncing on a laybarge stinger during adverse sea conditions. During pipeline trenching operations, coating damage has been known to occur due to contact with the trenching machine. Damage during installation should be minimized if adequate care is taken to ensure that installation takes place according to specified procedures.

In all cases noted above, the damage takes the form of physical coating removal over a particular area and consequent exposure of the pipe steel. Such damage may be accompanied by damage to the pipe wall itself.

During the operating lifetime of a pipeline, damage to coatings can be caused by external effects such as vessel anchors or cables. Such damage may lead to progressive breakdown or loss of coating. Corrosion coatings can also deteriorate due to inadequate preparation or poorly controlled application during pipeline fabrication.

Removal of corrosion coating is not likely to be wide-spread. Local removal will result in additional drain on the pipelines' cathodic protection system and localized corrosion of the pipe. The rate of corrosion will depend on the local conditions.

Coating damage can be repaired underwater as part of routine maintenance. There should be no need for emergency response.

#### **4.4.2 Weight Coating Damage**

Damage to weight coating can occur during pipeline installation or during operation. Damage encountered during transit for installation can also occur, but this should be and is generally repaired in accordance with applicable field repair specifications prior to the use of the pipe.

A common area for damage is during the passage of the pipeline between the installation vessel and the seabed. For example, weight coating can be fractured by bouncing on the rollers of a laybarge stinger during adverse sea conditions. During trenching, weight coating damage has been known to occur due to contact with the trenching machine. Damage during installation should be minimized if adequate care is taken to ensure that installation takes place according to specified procedures.

Weight coating damage takes the form of breakup and possible loss of the coating from the line. The ultimate outcome, if weight coating loss occurs over an extended length, will be flotation or an unstable pipeline.

During the operating lifetime of the pipeline, damage to the weight coating may occur due to external effects such as interaction with vessel anchors or cables. Such damage may lead to progressive breakdown or loss of the coating. A potential cause of serious weight coating damage is adverse vibration of a freespan in response to vortex shedding. Weight coating cracking and spalling from the pipe can be a result, accompanied by loss of pipeline vertical and horizontal stability in extreme cases.

Minor damage can normally be left unattended as long as it is confirmed that no damage to the pipewall has occurred. Where damage is due to span vibration, the span itself will require correction to arrest further vibration.

Where concrete loss is extensive, the stability of the pipeline will require checking the measures for provision of additional stabilization.

#### **4.4.3 Anode Damage, Loss or Depletion**

Anodes may be damaged or torn from the pipeline by the impact of construction anchors, cables, etc.

During the lifetime of the pipeline, drops in the system potential may be produced by depletion of anodes which subsequently require replacement

to maintain the effectiveness of the cathodic protection system. Although not truly damage, excess anode depletion can lead to enhanced corrosion.

Anode deficiency should be remedied as soon as is practical by anode retrofit or selection of alternative corrosion protection measures. Emergency response is not required.

## **4.5 DAMAGE OR FAILURE OF COMPONENTS**

### **4.5.1 Valves**

As an item containing moving parts, seals and a whole series of components, the valve can undergo a wide range of minor deficiencies through to total failure. Typically, damage can take the form of leaking seals, seal failure, actuator failure, corrosion or external damage by impact.

The consequences of valve damage can range from difficult operations of the valve through to severe leaking. Since the options for maintenance and repair are strongly linked to the valve type and manufacturer, the intervention requirements need to be determined on a case by case basis. For example, with ball valves, the valve type can be conventional, modular or in-situ repairable.

It can be concluded that the required intervention ranges from sealant injection for minor leakage to damaged valve removal and replacement with bypassing or shutdown of the pipeline system.

### **4.5.2 Flanges**

The primary damage associated with flanges is leakage due to improper sealing of the faces. The failure in sealing could be attributable to incorrect bolt tension, corrosion or undue bending placed on the flange connection. Other physical damage could occur to the flange due to impact.

Normally, flange leaks will allow escape of the pipeline contents at a rate similar to a pinhole leak or small hole in the pipeline. Although leakage is unacceptable, the intervention requirements do not necessarily qualify as needing emergency responses. Repair should be started as soon as possible by bolt tensioning. Should the leak continue, then replacement of the seal ring or entire flanged joint may be required.

### **4.5.3 Mechanical Connectors**

As a relatively complex component, the mechanical connector may develop leaks over a period of time. This may be due to internal corrosion or excessive axial or bending forces on the connector. Since the connecting mechanism is reversible on some systems but not on others, the course of action depends largely on the component in question. (Actual parting of a connector joint may be an outside possibility if the initial installation is inadequately performed).

Damage severity would be much the same as with a leaking flange. In-situ tightening of a mechanical connector may be feasible with some systems. In most cases, however, the leaking joint will require removal and replacement.

### **4.5.4 Flexible Pipeline Sections**

Flexible or composite pipe is being used increasingly for short infield flowlines, risers and for jumper connections. For the purposes of this manual, flexible pipe is categorized as a component for the reasons developed below. The pipe is of composite construction, typically being made up of a thermoplastic internal sheath, an interlocked steel carcass, an intermediate thermoplastic sheath, or a double layer of spiral wound steel armor, and an outer sheath of thermoplastic. End connections are fabricated (usually by hand) as units integral to the flexible pipe. This specialized construction makes it virtually impossible for repairs on flexible pipe to be made without changing out the affected section. Hence, the pipe is categorized as a component.

Damage to flexible pipe may occur due to buckling, breakdown of the internal structure with age and fatigue, external impact or excessive axial loadings. Instances of buckling damage have been attributed to inadequate control during installation.

The actual severity of damage will range from minor deterioration of the flexible pipe through to serious buckling and possible rupture. Should the level of damage be sufficient to require repair, then replacement of the affected section will be necessary and is usually the lower cost solution.

CATEGORIES	TYPES OF DAMAGE / DETERIORATION	DAMAGE SEVERITY LEVELS <div>1</div>	CAUSE OF DAMAGE																REPAIR REQUIREMENT					NOTES	KEY																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																													
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DAMAGE SEVERITY

LEVEL

- 1 SUPERFICIAL
- 2 SUBSTANTIAL
- 3 SUBSTANTIAL EXTERIOR
- 4 WALL DEFECT OR SMALL LEAK
- 5 SMALL HOLE OR SPLIT
- 6 LARGE HOLE OR RUPTURE

TABLE 4.1  
DAMAGE CATEGORIES

OVER STRESSING OR FATIGUE DAMAGE		PHYSICAL DAMAGE TO PIPE WALL										CATEGORIES																									
	OVER- PRESSURE	FATIGUE DAMAGE	SEVERE BENDING WITHOUT BUCKLING		DENT	BUCKLE	FRACTURE		TYPES OF DAMAGE / DETERIORATION	DAMAGE SEVERITY LEVELS <div>①</div>	CAUSE OF DAMAGE										REPAIR REQUIREMENT	NOTES	KEY														
											INTERNAL					EXTERNAL		ENVIRONMENTAL						DEFICIENCY													
											CORROSION	EROSION	EQUIPMENT FAILURE	OPERATOR ERROR	BLOCKAGE	DROPPED OBJECTS	ABRASION	CONSTRUCTION OPERATIONS	MILITARY OPERATIONS	EXTERNAL CORROSION	ANODE DEPLETION	SEVERE STORMS	EARTHQUAKE	SEABED MOVEMENT	SEABED INSTABILITY	LIQUEFACTION	MARINE GROWTH	DESIGN	MATERIALS/ FABRICATION	INSTALLATION	MONITORING MAINTENANCE	SYSTEM DERATING	MINOR INTERVENTION	INTERMEDIATE REPAIR	MAJOR REPAIR		

TABLE 4.1 (CONT.)  
DAMAGE CATEGORIES

①

DAMAGE SEVERITY

LEVEL

DAMAGE

1

SUPERFICIAL

2

SUBSTANTIAL

3

SUBSTANTIAL EXTERIOR

4

WALL DEFECT OR SMALL LEAK

5

SMALL HOLE OR SPLIT

6

LARGE HOLE OR RUPTURE

CATEGORIES	TYPES OF DAMAGE / DETERIORATION	DAMAGE SEVERITY LEVELS <div>1</div>	CAUSE OF DAMAGE														REPAIR REQUIREMENT				NOTES	KEY																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																										
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①

DAMAGE SEVERITY

- LEVEL
- DAMAGE
- 1 SUPERFICIAL
- 2 SUBSTANTIAL
- 3 SUBSTANTIAL EXTERIOR
- 4 WALL DEFECT OR SMALL LEAK
- 5 SMALL HOLE OR SPILT
- 6 LARGE HOLE OR RUPTURE

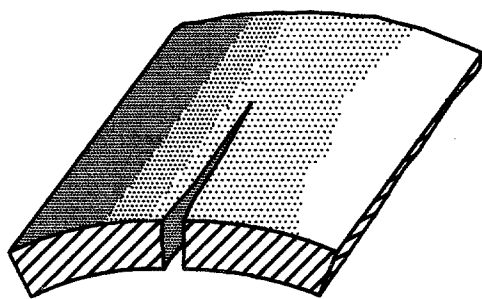
CAUSES ARE USUALLY RELATED TO VALVE COMPONENTS. REPLACEMENT, NOT REPAIR, IS REQUIRED.

CAUSES RELATED TO FLANGE BOLTS AND SEAL RING. REPAIR INCLUDES REPLACEMENT.

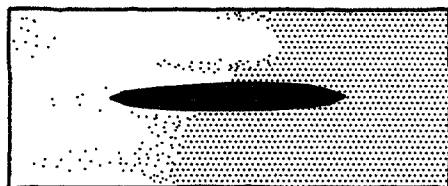
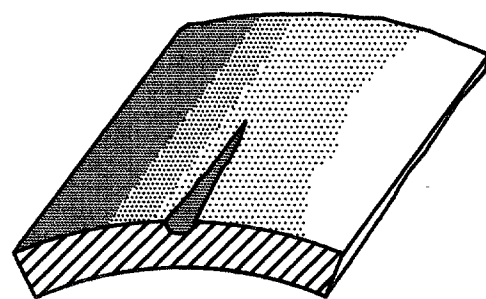
CAUSES USUALLY RELATED TO SEALS. DAMAGE IS HARD TO ACHIEVE.

TABLE 4.1 (CONT.)

DAMAGE CATEGORIES



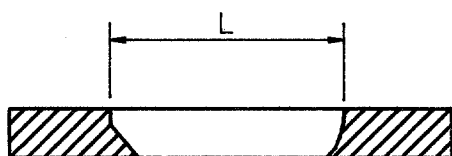
LONGITUDE AXIS  
OF PIPE



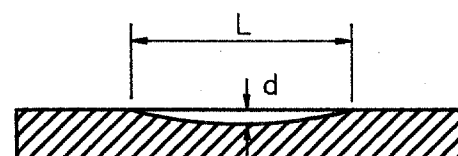
PLAN



PLAN



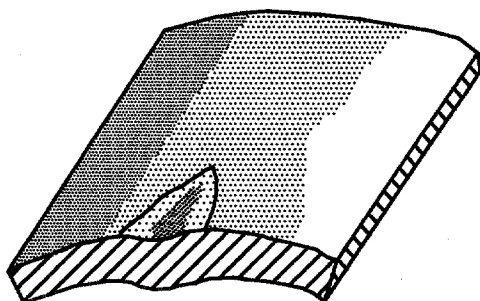
SECTION



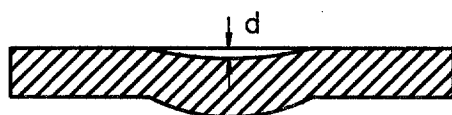
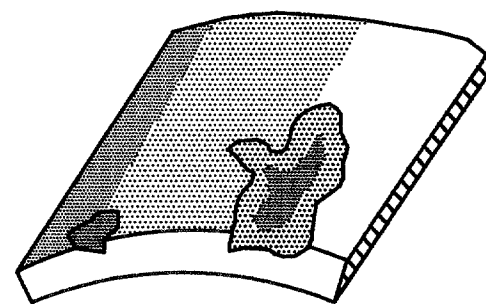
SECTION

THROUGH WALL FLAW

SURFACE FLAW/GOUGE



LONGITUDE AXIS  
OF PIPE



SECTION



SECTION

DENT

CORROSION DAMAGE



PROJECT

DEEPWATER PIPELINE  
MAINTENANCE AND  
REPAIR MANUAL

CLIENT:

MINERALS MANAGEMENT SERVICE

TITLE

TYPES OF DAMAGE  
TO PIPELINE WALL

SCALE:

1=1

JOB NO.:

2578.01

CAD FILE NO.:

2578-008.DWG

DOCUMENT NO.:

69-3-11-0

FIGURE NO.

4.1

CAD PLT SCALE:

1=1

## **Chapter Five**

### **MODES OF INTERVENTION**

## Chapter Five

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## Chapter Five

### MODES OF INTERVENTION

#### 5.1

#### INTRODUCTION

This Chapter of the manual presents modes of intervention for the purpose of detecting damage location and assessment, minor repair or major repair, where "intervention" describes a corrective or preventative action. The following sections are limited to intervention by subsurface means and do not include surface methods such as towed seismic or ship-mounted sonar data gathering. Remote instrumentation, such as subsurface towed sonar or sub-bottom profile equipment, is likewise excluded. These damage location methods are discussed in Chapter Six. The methods of accessing a subsea pipeline system discussed are:

- Divers;
- Remotely Operated Vehicles; and
- Manned Submersibles.

Prior to more detailed discussion of the methods, it is important to note that depth constraints are a key factor in defining the specific capabilities and limitations of repair techniques. The general depth constraints are:

- Saturation diving - 1500 feet;
- One-atmospheric diving suit - 2300 feet;
- Manned submersible - 2600 feet;
- Unmanned submersible - 3300 feet;
- Multi-manned submersible - 8300 plus feet;
- Unmanned, tethered vehicle - 6500 feet; and
- Unmanned, untethered vehicle - 25,000 feet.

This Chapter is included to aid in the definitions of limitations as a prelude to the detailed presentations of the available repair techniques in Chapters Seven and Eight.

## **5.2 DIVER INTERVENTION**

Diving intervention for the purpose of damage location, assessment, and repair is limited to saturation diving for water depths to 1500 feet. An outline of the diving functions is given followed by a description of saturation diving and a discussion of current research on the extension of operational diving limits and working diver capabilities.

### **5.2.1 Diving Functions**

The following diving tasks are associated with the location and assessment of damage and typical repair of pipeline systems:

- inspection of pipelines and risers for spanning, corrosion coating damage, weight coating damage, corrosion, buckling and visible pipe wall damage;
- repair of coating damage by patching or span correction;
- cutting to remove damaged pipe sections for replacement;
- retrofit or replacement of anodes;
- measuring offsets and distances required for spoolpiece installation;
- rigging associated with aligning pipe ends for flanged or mechanical connection or installation of a weld habitat; and
- Pipeline section replacement and connection by bolting, mechanical connector or welding subsea.

This list is representative of the main diving functions, but is certainly not exhaustive.

### **5.2.2 Saturation Diving**

Saturation diving is required for intervention to depths beyond 800 feet and involves the provision of hyperbaric living chambers aboard the dive vessel maintained at a pressure near that of the work site for the dive team. By remaining near the working depth or equivalent pressure for the duration of the task, the dive team must undergo only one final decompression.

Therefore, physical fatigue replaces bottom time as the limiting factor in work output per diver. It is possible for divers to be on bottom 18 hours per day by utilizing up to three shift crews in saturation.

The physical plant required to support divers in saturation is quite extensive and varies with the number of divers comprising the team. Living chambers are designed to house the teams and these chambers can be linked together into a complex chain for the number of divers on the team.

An extensive control system is required to monitor the breathing mixtures supplied to the chambers. Gas from the chambers is continuously recirculated and regenerated. Pressure level and temperature, as well as the level of each of the components, are continuously measured.

Currently, saturation diving to a depth of 1500 feet is considered operationally feasible, although the body of work which has been accomplished below 1000 feet is limited. Saturation diving is fairly routine to depths of 650-700 feet, since numerous offshore developments have occurred to this depth. Significant tasks have been performed to depths of 1000-1200 feet, but the smaller number of facilities placed at these depths until recently has generated a limited demand for intervention.

Saturation diving is less depth sensitive than other diving modes in terms of manpower requirements. Diving crew size is more a function of a subsea task to be performed than working depth, as bottom time is not depth limited. However, the saturation system becomes more complex with depth, thus contributing to the crew size topside. Saturation diving for a task at 200 feet depth is quite similar for the same task at 1000 feet. The physical plant required for gas reclamation and treatment becomes increasingly complex with depth, as well as the associated equipment supplying heating for the breathing gas and diving suits and the emergency gas supply system.

At depths greater than 1000 feet, current technology regarding diving physiology and diving hardware reaches practical limits. Diver stress levels associated with the performance of standard work tasks increase due to the exertion required to breath the dense gases supplied at depth. The systems required to supply adequate emergency breathing gas become increasingly complex, since gas reclamation apparatus must be included. A standard bailout system will supply three to four draws of gas (breaths) at 1000 feet.

Additionally, emergency systems for maintaining body temperature become increasingly important, as the interval prior to onset of hypothermia is brief in many regions of the world's oceans.

### 5.2.3 Diving Research

Current and proposed research places an emphasis on improving diving intervention in the depth range currently considered fully operational and on developing methods for extending the depth to which man can descend and perform significant work. Topics subject to current studies include breathing gas mixtures, oxygen toxicity, diving hardware, High Pressure Nervous Syndrome (HPNS) and open water depth testing.

The study of breathing gas mixtures fulfills a dual role, to increase diver comfort and efficiency at operational depths as well as to extend current depth limitations.

For more than 25 years, most commercial dives to 1000 feet have utilized a helium (He) and oxygen (O<sub>2</sub>) mixture, Heliox; but below 1000 feet the effect of HPNS and increased breathing difficulty greatly impaired work capacity. Gas mixtures adding hydrogen (H<sub>2</sub>) or nitrogen (N<sub>2</sub>) to Heliox have been studied and successfully tested. These include Hydrox (H<sub>2</sub>, O<sub>2</sub>), Hydrellox (H<sub>2</sub>, He, O<sub>2</sub>) and Trimix (He, N<sub>2</sub>, O<sub>2</sub>). Hydrox has been tested to 750 feet, Hydrellox to 1500 feet and Trimix to 2100 feet each with varying degrees of HPNS and breathing difficulty effects. Continuing research to increase operational depth limits focuses on optimization of the gas mixtures composition.

Another related area of study concerns further defining human tolerance to oxygen and reaction to oxygen as a poison at elevated pressure. The guidelines presently in use are based on work performed up to 20 years ago. The goal of present research is repeal of over-conservative oxygen tolerance limits. Determining the allowable limits may increase the safe time spent at depth and provide more effective use of oxygen in decompression and in the treatment of diving related illnesses.

Ottestad Breathing Systems, a European manufacturer of deepwater breathing systems has studied the effects of heat loss through the respiratory tract and developed breathing equipment which provides warm, saturated gases, has a high flow capacity regardless of depth, and is self regulating. The system has been tested to 1300 feet and appears to also aid in the treatment of decompression sickness. The equipment is based

on a pneumatic controlled lung which features a low pressure demand regulator to ease breathing and is totally independent of all topside facilities. All equipment fits in a low weight backpack which is neutrally buoyant.

Improvements in the hardware associated with breathing gas regeneration will serve to increase diver productivity through reduced exertion and serve to extend operational depths. Advances are required in gas filtration systems and valve flow characteristics. Emergency air supply (bailout) systems will require modification or redesign as working depths continue extend beyond 1000 feet. Results from some studies indicated that heavy saturation diving equipment already developed for helium can be modified for hydrogen use with relative ease and minimal costs while maintaining all safety guarantees.

### **5.3 SUBMERSIBLE INTERVENTION**

Extreme water depth and prevailing weather conditions can dictate that operations normally performed by divers be modified to allow operation by alternative methods. This section examines possible intervention techniques and assesses their applicability and suitability to necessary tasks.

Two types of equipment are examined as alternative intervention methods:

- 1) remotely operated vehicles (ROVs); and
- 2) manned submersibles.

Key features and pertinent information on specific systems in these categories are provided in data sheets found at the end of this Chapter. The descriptions set out below are for multi-purpose production type ROVs and submersible systems. Certain specialized systems are under development, specifically for pipeline repair. These 'integrated' systems are discussed in Section 8.5.

#### **5.3.1 Remotely Operated Vehicles (ROVs)**

##### **5.3.1.1 Overview of ROVs**

The number of free-swimming ROVs built has increased substantially since they first appeared in the late 1960's. One of the reasons for this growth is the operators demands for increased sophistication and requirements of ROVs. In order to gain general acceptance within the offshore industry, ROVs have to keep ahead of these requirements. In the mid-1980's, the

degree of sophistication for inspection ROVs with videos and sensors seemed to approach its apex. Improvements in the capabilities of these machines are now more dependent on refinement of the cameras and on-board equipment than on the machine itself.

ROVs designed to replace diver tasks are, however, at an intermediate stage of development. Modifications are still being examined by manufacturers to improve ROV versatility and dexterity in replacing the operations of a diver.

Where these manipulative ROVs take precedence is in their ability to operate at depths prohibitive to diver intervention. At depths of 1000 feet, the work of divers is limited to simple short duration tasks which may be inadequate for repair operations. At about 1500 feet, open water diver intervention is no longer viable owing to the high hydrostatic pressure and other depth related problems.

A survey of the most common manipulative ROVs indicates that the facilities each one offers are essentially the same. These are generally based on a modular design with the ROV unit as a basically neutrally buoyant frame which can be propelled by thrusters. This unit can be attached to a variety of devices dependent on the intended use of the ROV. Several modular ROVs currently available are described in the data sheets following this Chapter.

A major limitation of ROV maneuverability is the need for a tether to the surface. A tether restricts the movement of an ROV by its drag as it is forced to track after the ROV. It is also possible for the tether to become snagged on an obstruction on the seabed. Tether management systems have been developed, however, and are now offered as an option on most ROVs. The ROV is connected to a cage or garage by an umbilical and is deployed inside the cage to the work site. At the work site, the ROV is released and maneuvers within a working radius that varies with the type and size of the ROV as the cage remains virtually stationary.

Autonomous ROVs overcome the problems arising from an absence of surface connection as follows:

- They have very little equipment and do not require a high power input;
- they can be pre-programmed to locate their target and position themselves with the aid of sensors; and
- they can store information on-board or transmit it to the surface using low energy techniques such as slow scan TV.

The current power requirements of modular ROVs eliminates the possibility of acquiring autonomy.

#### 5.3.1.2

##### Capabilities

The range of equipment that general purpose modular ROVs carry is outlined below. For specific repair work, extra items can be added or even developed depending on the requirements of the operator:

- manipulator arm;
- scanning sonar;
- specialist TV cameras;
- stereo still camera;
- automatic depth-keeping and heading capabilities;
- gyroscope;
- variable intensity high power lights;
- depth transducer; and
- monitor for inspection of on-board equipment status.

Of particular interest are the manipulators capable of performing repair tasks usually executed by divers. Manipulators are now at a stage of development where their dexterity is comparable with that of a human arm. The most advanced have seven degrees of freedom which are as follows:

- 1) hand grip;
- 2) wrist up - down motion;
- 3) wrist side - side motion;
- 4) wrist axially rotate (twist);
- 5) elbow hinge;
- 6) shoulder up - down motion; and
- 7) shoulder side - side motion.

The ability of manipulators to "feel" pressure or force is known as tactility. This facility has been introduced into advanced manipulators and signifies

that the ROV can sense when it is gripping an object securely rather than having to rely on visual confirmation. Tactility is beneficial in delicate operations where the application of too much force may cause damage.

Manipulator arms are capable of providing limited torque to assist with bolting operations. Standard equipment is capable of providing at least 80 ft-lb; although for the final torquing of a bolt, specialized equipment must be attached. To apply high torques, the ROV will need to anchor itself to a firm foundation to prevent itself from rotating in reaction to the applied torque. This may involve a claw or a second manipulator. Only a low degree of dexterity would be required for the second manipulator.

The range of repair associated operations that can be performed by a heavy work type ROV is as follows:

- damage location and assessment;
- pipe cutting;
- pipe grinding;
- cable cutting;
- operation of hydraulic tools;
- water jetting;
- seal replacement;
- flange seal repair;
- anode retrofit;
- rig and platform support; and
- valve maintenance (seal replacement).

#### 5.3.1.3

##### Environmental Constraints

ROV operations may be influenced by the effects of depth and currents. The depths in which current and planned pipelines of the near future are installed, or to be installed, are not really a major obstacle to ROVs. Currently, depths on the order of 6500 feet can be negotiated without problem. Greater depths can easily be achieved simply by upgrading those parts of the ROV which are susceptible to high pressures. Some specialist inspection ROVs currently have a 20,000 feet depth capability. The tether length at great depths restricts movement of the ROV due to increased inertia and drag forces. This can be overcome by conveying the ROV to the work location in a tether management system. For deepwater work, steady state currents are rarely greater than 0.3 knots. Most ROVs are designed to operate adequately in currents up to about 2 to 3 knots.

Typically, insurance requirements dictate that ROVs used in conditions worse than Sea State 6 are at the operator's own risk. However, ROVs have been used successfully in up to Sea State 10. It is only during surface work that waves significantly influence ROV operations; at depth, the limitations of the support vessel are more likely to be a governing factor.

### 5.3.2 Manned Submersibles

#### 5.3.2.1 Overview

The development of manned submersibles has progressed in a similar manner to that of ROVs for deepwater pipeline repair tasks. Some vehicles are now manufactured to operate in a dual role with the option of either carrying a man or carrying additional equipment and relying on remote control. Consequently, the division between manned and unmanned vehicles is becoming less distinct.

Manned submersibles are available in a variety of designs which include:

- one-atmosphere diving suits (ADS);
- manned (or dual purpose) submersible; and
- multi-manned submersible.

The ADS design extends the principle of a diving suit to deepwater applications. It is a rigid shell that surrounds a diver and can withstand hydrostatic pressure to maintain the inside at one atmosphere. The suit has a bulky humanoid appearance with thrusters or legs and its current capability of 2300 feet has not increased much since the mid 1980's. It therefore seems probable that this limit can be extended to 2500 feet without much problem. A typical suit is shown in Figure 5-1.

The dual purpose manned design is very similar in appearance to typical ROVs. The main difference is the presence of a shell in which a person can habituate; this dictates the slightly larger overall dimensions. The current maximum depth rating for a typical dual purpose submersible is 2600 feet when operating in the manned mode.

The third submersible design includes those vehicles capable of housing two or more people. The multi-manned submersibles range from small bell-like vehicles to large submarine vessels capable of carrying a crew of five or more. The larger vessels tend to be for specialized jobs such as wellhead repair and are suitable for pipeline repair as well. The majority of large multi-manned submersibles have been depth limitations of around

1000 feet. However there are deepwater versions with operational depth ratings of up to 6600 feet and observation type unmanned, untethered submersibles have worked to 25,000 feet.

#### 5.3.2.2 Capabilities

The limitations and capabilities of manned submersibles are generally similar to those of ROVs; however, the depth limitations for manned submersibles on a whole are less than those for ROVs. The essential differences which may favor one type of vehicle over another are outlined in the data sheets found at the end of this Chapter.

The need to house a person within the body of the submersible results in a vehicle that is bulkier and heavier than it otherwise might be. ADS systems overcome this obstacle at the expense of on-board equipment.

The consequences of umbilical severance or other damage are much more disastrous for a manned vehicle especially when concerning deepwater pipeline repair where rapid recovery of the vehicle is impossible. The expense of employing a diver to venture to such depths in a manned submersible may also be considerable.

Only a few submersibles are capable of descending below 2600 feet. However, the few submersibles that are capable of operating at these depths have been used extensively worldwide in recent years.

One beneficial aspect of manned submersibles is the lack of reliance on cameras to record subsea operations. The presence of the vehicle operator next to the intended task may simplify the resolution of any complications that may arise.

### 5.4 **DATA SHEETS AND MATRICES**

The following data sheets are presented to relate pertinent information on diving, ROV and manned submersible systems. The data sheet format and referencing system is as outlined in Chapter Three. Table 5.1 presents a comparison matrix which summarizes the key attributes of diving, ROV and manned submersible modes of intervention.

Table 5.2 gives more detail on individual ROV and manned submersible types. This table is not exhaustive and is intended to demonstrate the capabilities of some of the more widely used systems currently available.

# DATA SHEET

REFERENCE: 5.2-1

AREA: Modes of Intervention

CATEGORY: Divers

TECHNIQUE: Saturation Diving

DESCRIPTION: Diver is deployed using a closed bell from a surface support hyperbaric chamber

## KEY PARAMETERS:

- PIPE DIAMETER: N/A
- MAXIMUM WATER DEPTH: 1000 feet working; 1500 feet max.
- MODE OF INTERVENTION: Diver
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Extensive to 1000 feet; limited beyond

## ADDITIONAL INFORMATION:

- Crew: 4 saturation divers 2 engineer  
1 superintendent 8 tender  
2 supervisor 2 stand-by diver  
2 technician
- Saturation Period: Approximately 1 day/100 feet depth
- Required Equipment: Bell handling system; deck living chambers complex; chamber controls; scrubber to remove CO<sub>2</sub>; gas mixture blender; transfer chamber; diving bell
- Vessel: 110-210 feet barge or diving support vessel with 4-point mooring system
- Operators: American Oilfield Divers  
Cal Dive  
Global Divers  
Oceaneering

REFERENCE: Section 5.2

# DATA SHEET

REFERENCE: 5.3-1

AREA: Modes of Intervention

CATEGORY: Work Vehicles

TECHNIQUE: Gemini

DESCRIPTION: Tethered work vessel for deepwater

## KEY PARAMETERS:

- PIPE DIAMETER: N/A
- MAXIMUM WATER DEPTH: 5000 feet
- MODE OF INTERVENTION: ROV
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Extensive

## ADDITIONAL INFORMATION:

- Dimensions: 8.9 x 6.0 x 5.8 feet
- Weight: 4300 lbs
- Payload: 400 lbs
- Lift Capacity: 1500 lbs
- Features: 7 thrusters; 1 x 7 manipulators; 2 cameras; 1000 W lightning; sonar
- Options: Cable cutter; water jet
- Operator: Oceaneering
- Supplier: Oceaneering

REFERENCE: 5.3.1

# DATA SHEET

REFERENCE: 5.3-2

AREA: Modes of Intervention

CATEGORY: Work Vehicles

TECHNIQUE: HYDRA

DESCRIPTION: Tethered high thrust/payload work vessel

## KEY PARAMETERS:

- PIPE DIAMETER: N/A
- MAXIMUM WATER DEPTH: 8200 feet
- MODE OF INTERVENTION: ROV
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Extensive

## ADDITIONAL INFORMATION:

- Dimensions: 5.9 x 3.9 x 4.3 feet
- Weight: 1900 lbs
- Payload: 200 lbs
- Lift Capacity: 250 lbs
- Features: 4 thrusters; 1 x 5, 1 x 7 manipulators; 4 x 250 W lights; 3 cameras; sonar; flux gate compass; tether management system (350 feet radius); telemetry
- Options: 1 camera; wire cutting tools; rotary cut-off tools; wenchers; AX-ring tool; water jets; shackling/bolting capability
- Operator: Oceaneering
- Supplier: International Submarine Engineering

REFERENCE: Section 5.3.1

# DATA SHEET

REFERENCE: 5.3-3

AREA: Modes of Intervention

CATEGORY: Work Vehicles

SYSTEM: MAGELLAN - 725

DESCRIPTION: Tethered, deepwater search and salvage vessel

## KEY PARAMETERS:

- PIPE DIAMETER: N/A
- MAXIMUM WATER DEPTH: 25,000 feet
- MODE OF INTERVENTION: ROV
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Extensive

## ADDITIONAL INFORMATION:

- Dimensions: 8.0 x 5.0 x 5.0 feet
- Weight: 3500 lbs
- Payload: 200 lbs
- Lift Capacity: Unknown
- Features: 7 thrusters; 1 x 5, 1 x 7 function manipulators; 5 x 250 W lights; long range sonar; cutters; tether management system
- Options: 4 camera; hydraulic hotstab unit; CP probe; pipe tracking system; inclinometer; cable gripper
- Operator: Eastport International
- Supplier: Eastport International

REFERENCE: Section 5.3.1

# DATA SHEET

REFERENCE: 5.3-4

AREA: Modes of Intervention

CATEGORY: Work Vehicles

TECHNIQUE: Pioneer

DESCRIPTION: Tethered work vessel for drilling support

## KEY PARAMETERS:

- PIPE DIAMETER: N/A
- MAXIMUM WATER DEPTH: 3000 feet working; 6000 feet max.
- MODE OF INTERVENTION: ROV
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Extensive

## ADDITIONAL INFORMATION:

- Dimensions: 5.4 x 5.4 x 5.4 feet
- Weight: 3300 lbs
- Payload: 200 lbs
- Lift Capacity: 500 lbs
- Features: 5 thrusters; 1 x 5, 1 x 7 function manipulators; 2 cameras; 4 x 1000 W lights; sonar; depth sensor; slivable gyro; telemetry; pinger; emergency strobe
- Options: 2000 W additional lighting; transponder; cutter
- Operator: SubSea International
- Supplier: SubSea International

REFERENCE: Section 5.3.1

# DATA SHEET

**REFERENCE:** 5.3-5

**AREA:** Modes of Intervention

**CATEGORY:** Work Vehicles

**SYSTEM:** Recon IV

**DESCRIPTION:** Tethered work vessel

## KEY PARAMETERS:

- **PIPE DIAMETER:** N/A
- **MAXIMUM WATER DEPTH:** 2300 feet
- **MODE OF INTERVENTION:** ROV
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive

## ADDITIONAL INFORMATION:

- **Dimensions:** 6.5 x 3.0 x 2.75 feet
- **Weight:** 900 lbs
- **Payload:** 250 lbs
- **Lift Capacity:** 400 lbs
- **Features:** 4 thrusters; 1 x 4 function manipulator; 3 cameras; 4 x 250 W lights; tether management system (400 feet radius); magnetic compass; depth sensor; NDT inspection
- **Options:** Twin manipulator/anode placement package; pipe tracking and cathodic protection survey systems; cutter; grinder; wire brush
- **Operator:** International Underwater Contractors
- **Supplier:** Perry Technologies

**REFERENCE:** Section 5.3.1

# DATA SHEET

**REFERENCE:** 5.3-6

**AREA:** Modes of Intervention

**CATEGORY:** Work Vehicles

**SYSTEM:** Rigworker R3000

**DESCRIPTION:** Tethered work vessel for drilling support

## KEY PARAMETERS:

- **PIPE DIAMETER:** N/A
- **MAXIMUM WATER DEPTH:** 3280 feet
- **MODE OF INTERVENTION:** ROV
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive

## ADDITIONAL INFORMATION:

- **Dimensions:** 7.9 x 5.6 x 4.6 feet
- **Weight:** 2425 lbs
- **Payload:** 187 lbs
- **Features:** 8 thrusters; 1 x 6 function manipulator; 2 cameras; 3700 W lighting; depth guage; altimeter; sonar; cutter
- **Options:** 1 x 7 function manipulator; drilling support tool; dredging tool; inspection module; bathymetric system; scanning profiler; gyro; odometer
- **Operator:** Rockwater
- **Supplier:** OSEL Offshore Systems Engineering Ltd.

**REFERENCE:** Section 5.3.1

# DATA SHEET

**REFERENCE:** 5.3-7

**AREA:** Modes of Intervention

**CATEGORY:** Work Vehicles

**SYSTEM:** Scorpio Plus

**DESCRIPTION:** Tethered work vessel for drilling support

## KEY PARAMETERS:

- PIPE DIAMETER: N/A
- MAXIMUM WATER DEPTH: 3000 feet
- MODE OF INTERVENTION: ROV
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Extensive

## ADDITIONAL INFORMATION:

- Dimensions: 6.2 x 5.8 x 8.2 feet
- Weight: 2200 lbs
- Payload: 200 lbs
- Lift Capacity: 400 lbs
- Features: 4 thrusters; 1 x 5, 1 x 7 function manipulators; 2 cameras; 3 x 250 W lights; sonar; depth sensor; slivable gyro; pinger; emergency strobe
- Operator: SubSea International
- Supplier: SubSea International

**REFERENCE:** Section 5.3.1

# DATA SHEET

**REFERENCE:** 5.3-8

**AREA:** Modes of Intervention

**CATEGORY:** Inspection Vehicles

**SYSTEM:** Dragonfly

**DESCRIPTION:** Tethered inspected vessel for deepwater

## KEY PARAMETERS:

- **PIPE DIAMETER:** N/A
- **MAXIMUM WATER DEPTH:** 6562 feet
- **MODE OF INTERVENTION:** ROV
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Limited

## ADDITIONAL INFORMATION:

- **Dimensions:** 8.3 x 6.0 x 3.5 feet
- **Weight:** 3500 lbs
- **Payload:** 1000 lbs
- **Lift Capacity:** Unknown
- **Features:** 6 thrusters; 2 x 7 function manipulators; 6 cameras; 3000 W lighting; pressure transducers; gyro; echo sounder
- **Options:** Pinger; sonar
- **Operator:** Bue Marine Division
- **Supplier:** OSEL Offshore Systems Engineering Ltd.

**REFERENCE:** Section 5.3.1

# DATA SHEET

**REFERENCE:** 5.3-9

**AREA:** Modes of Intervention

**CATEGORY:** Work Vehicles

**SYSTEM:** SeaRover (Openframe)

**DESCRIPTION:** Tethered work vessel

## KEY PARAMETERS:

- **PIPE DIAMETER:** N/A
- **MAXIMUM WATER DEPTH:** 1000 feet: \_\_\_\_ feet max.
- **MODE OF INTERVENTION:** ROV
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive

## ADDITIONAL INFORMATION:

- **Dimensions:** 4.2 X 2.3 X 2.3 feet
- **Weight:** 310 lbs
- **Payload:** 90 lbs
- **Features:** 6 thrusters; 1 camera; 2 X 150 W lights, depth sensor
- **Options:** Sonar: multi-function articulators; tether management system; video cameras; altimeter
- **Operator:** United States Navy
- **Supplier:** Benthos Undersea System Technology

**REFERENCE:** Section 5.3.1

# DATA SHEET

**REFERENCE:** 5.3-10

**AREA:** Modes of Intervention

**CATEGORY:** Inspection Vehicles

**SYSTEM:** RCV 225c

**DESCRIPTION:** Tethered inspection vessel for drilling operations and platform/  
vessel inspections

## KEY PARAMETERS:

- **PIPE DIAMETER:** N/A
- **MAXIMUM WATER DEPTH:** 1350 feet
- **MODE OF INTERVENTION:** ROV
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive

## ADDITIONAL INFORMATION:

- **Dimensions:** 1.7 x 2.2 x 1.7 feet
- **Weight:** 180 lbs
- **Features:** 4 thrusters; 1 camera; 2 x 45 W lights; depth sensor; heading sensor; compass; tether management system (410 feet radius)
- **Options:** Transponder; tag manipulator; 1 x 250 W light; hydrophone; sonar
- **Operator:** Rockwater
- **Supplier:** Hydro Products

**REFERENCE:** Section 5.3.1

# DATA SHEET

REFERENCE: 5.3-11

AREA: Modes of Intervention

CATEGORY: Inspection Vehicles

SYSTEM: UFO 350c

DESCRIPTION: Tethered inspection vessel

## KEY PARAMETERS:

- PIPE DIAMETER: N/A
- MAXIMUM WATER DEPTH: 1350 feet
- MODE OF INTERVENTION: ROV
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Extensive

## ADDITIONAL INFORMATION:

- Dimensions: 4.0 x 2.5 x 1.6 feet
- Weight: 317 lbs
- Features: 4 thrusters; 2 cameras; 4 x 150 W lights; tether management system (380 feet radius)
- Options: Depth sensor; transponder; sonar; echo locator; oil leak detection system; 300 W additional lighting
- Operator: Rockwater
- Supplier: OSEL Offshore Systems Engineering Ltd.

REFERENCE: Section 5.3.1

# DATA SHEET

**REFERENCE:** 5.3-12

**AREA:** Modes of Intervention

**CATEGORY:** Combination Work/  
Inspection Vehicles

**SYSTEM:** HYSUB - 25

**DESCRIPTION:** Tethered, vessel for pipeline and platform inspection and drill rig support

## KEY PARAMETERS:

- PIPE DIAMETER: N/A
- MAXIMUM WATER DEPTH: 5000 feet
- MODE OF INTERVENTION: ROV
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Extensive

## ADDITIONAL INFORMATION:

- Dimensions: 7.5 x 3.5 x 3.7 feet
- Weight: 2000 lbs
- Payload: 200 lbs
- Lift Capacity: Unknown
- Features: 6 thrusters; 1 x 6 function manipulator; 3 cameras; 5 x 250 W lights; sonar; cutters; tether management system
- Options: 1 x 4, 5, 6 or 7 function manipulator; 3 cameras; hydraulic hotstab unit; CP probe; depth transducer; pipe tracking system; inclinometer; cable gripper
- Operator: Eastport International
- Supplier: Eastport International

**REFERENCE:** Section 5.3.1

# DATA SHEET

**REFERENCE:** 5.3-13

**AREA:** Modes of Intervention

**CATEGORY:** Combination Work/  
Inspection Vehicles

**SYSTEM:** SCORPIO - 1000

**DESCRIPTION:** Tethered vessel for pipeline and platform inspection and drill rig support

## KEY PARAMETERS:

- PIPE DIAMETER: N/A
- MAXIMUM WATER DEPTH: 3280 feet
- MODE OF INTERVENTION: ROV
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Extensive

## ADDITIONAL INFORMATION:

- Dimensions: 6.5 x 3.3 x 3.7 feet
- Weight: 1500 lbs
- Payload: 100 lbs
- Lift Capacity: Unknown
- Features: 5 thrusters; 1 x 5 function manipulator; 3 cameras; 5 x 250 W lights; sonar; cutters; tether management system
- Options: 1 x 4, 5, 6 or 7 function manipulator; 3 cameras; hydraulic hotstab unit; CP probe; depth transducer; pipe tracking system; inclinometer; cable gripper
- Operator: Eastport International
- Supplier: Eastport International

**REFERENCE:** Section 5.3.1

# DATA SHEET

**REFERENCE:** 5.3-14

**AREA:** Modes of Intervention

**CATEGORY:** Atmospheric Diving Suits

**SYSTEM:** Hornet

**DESCRIPTION:** Tethered, one-atmospheric diving suit for deepwater work

## KEY PARAMETERS:

- **PIPE DIAMETER:** N/A
- **MAXIMUM WATER DEPTH:** 2300 feet
- **MODE OF INTERVENTION:** Manned Submersible
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive

## ADDITIONAL INFORMATION:

- **Crew:** 1 pilot
- **Life Support:** 80 hours
- **Features:** 2 thrusters; 2 jaws grip arms; hard wire and ultrasonic communications; camera; wide angle hemispherical viewport; foot pedal control
- **Other:** 1 x 6 function manipulator; 400 feet working radius
- **Operator:** Oceaneering
- **Supplier:** OSEL Offshore Systems Engineering Ltd.

**REFERENCE:** Section 5.3.2

# DATA SHEET

REFERENCE: 5.3-15

AREA: Modes of Intervention

CATEGORY: Atmospheric Diving Suits

SYSTEM: Newtsuit

DESCRIPTION: Tethered or free swimming, one-atmospheric diving suit with arms and legs

## KEY PARAMETERS:

- PIPE DIAMETER: N/A
- MAXIMUM WATER DEPTH: 1000 feet
- MODE OF INTERVENTION: Manned Submersible
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Limited

## ADDITIONAL INFORMATION:

- Crew: 1 pilot
- Life Support: 48 hours (2 independent closed circuit systems)
- Features: 2 thrusters; fully articulated arms and legs with rotary joints; hard wired and acoustic communications; interchangeable manipulators; wide angle hemispherical viewport; hull split at waist
- Other: 200 sq feet deck space required
- Operator: Underwater Atmospheric Systems
- Supplier: International Hard Suits

REFERENCE: Section 5.3.2

# DATA SHEET

REFERENCE: 5.3-16

AREA: Modes of Intervention

CATEGORY: Atmospheric Diving Suits

TECHNIQUE: WASP 2A

DESCRIPTION: Tethered, one-atmospheric diving suit for deepwater work

## KEY PARAMETERS:

- PIPE DIAMETER: N/A
- MAXIMUM WATER DEPTH: 2300 feet
- MODE OF INTERVENTION: Manned Submersible
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Extensive

## ADDITIONAL INFORMATION:

- Crew: 1 pilot
- Life Support: 72 hours
- Features: 4 thrusters; 2 articulated arms; hard wire and acoustic communications; hemispherical dome viewport; beacon; tracker; emergency onboard battery; foot pedal control
- Other: 400 sq feet deck space required including 2 winches, power pack, deployment system, and spare equipment
- Operator: Oceaneering
- Supplier: OSEL Offshore Systems Engineering Ltd.

REFERENCE: Section 5.3.2

# DATA SHEET

**REFERENCE:** 5.3-17

**AREA:** Modes of Intervention

**CATEGORY:** Dual Purpose

**SYSTEM:** DUPLUS II

**DESCRIPTION:** Tethered work vessel or one-atmosphere diving suit for deepwater

## KEY PARAMETERS:

- **PIPE DIAMETER:** N/A
- **MAXIMUM WATER DEPTH:** 2625 feet (manned); 3280 feet (remote)
- **MODE OF INTERVENTION:** Manned Submersible
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive

## ADDITIONAL INFORMATION:

- **Crew:** 1 pilot or remote
- **Life Support:** 72 hours
- **Payload:** 220 lbs (manned); 440 lbs (remote)
- **Lift Capacity:** 66 lbs (each manipulator)
- **Features:** 10 thrusters; 1 x 6, 1 x 7 function manipulators; 1 x 3 function grabber arm; 1 camera; wide angle hemispherical viewport; depth sensor; gyro; echo sounder; self monitoring system
- **Operator:** Scandive
- **Supplier:** OSEL Offshore Systems Engineering Ltd.

**REFERENCE:** Section 5.3.2

# DATA SHEET

REFERENCE: 5.3-18

AREA: Modes of Intervention

CATEGORY: Dual Purpose

SYSTEM: Mantis

DESCRIPTION: Free - swimming, one-atmosphere diving suit or work vessel for deepwater

## KEY PARAMETERS:

- PIPE DIAMETER: N/A
- MAXIMUM WATER DEPTH: 2300 feet
- MODE OF INTERVENTION: Manned Submersible
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Extensive

## ADDITIONAL INFORMATION:

- Crew: 1 pilot or unmanned
- Life Support: 96 hours
- Payload: 440 lbs
- Lift Capacity: 50 lbs
- Features: 12 thrusters; 2 x 6 function manipulators; hard wire and acoustic communicators; wide angle hemispherical viewport; sonar; pinger; gyro; compass; echo sounder; water jet; cable cutter; wirebrush
- Operator: International Underwater Contractors
- Supplier: OSEL Offshore Systems Engineering Ltd.

REFERENCE: Section 5.3.2

# DATA SHEET

**REFERENCE:** 5.3-19

**AREA:** Modes of Intervention

**CATEGORY:** Multi-Manned  
Submersibles

**SYSTEMS:** OSS 1500

**DESCRIPTION:** Manned autonomous submarine for tasks on deepwater installations

## KEY PARAMETERS:

- **PIPE DIAMETER:** N/A
- **MAXIMUM WATER DEPTH:** 4921 feet
- **MODE OF INTERVENTION:** Manned Submersible
- **AVAILABILITY:** Brazil
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Limited

## ADDITIONAL INFORMATION:

- **Crew:** 5 persons
- **Life Support:** 120 hours
- **Payload:** 20 tons
- **Features:** 34 x 23 x 26 feet cargo hold containing a 25 ton capacity crane/work module with 2 x 7 function manipulators; sonar; pinger; sampling tools; anode and transponder installation/repair tools; wireline capabilities; pipe/cable cutter and connection tools
- **Options:** Drone ROV for light work
- **Operator:** Thyssen Nordseewerke GmbH
- **Supplier:** Thyssen Nordseewerke GmbH

**REFERENCE:** Section 5.3.2

# DATA SHEET

**REFERENCE:** 5.3-20

**AREA:** Modes of Intervention

**CATEGORY:** Multi-Manned  
Submersibles

**SYSTEM:** Pisces VI

**DESCRIPTION:** Free - swimming deepwater work submersible

## KEY PARAMETERS:

- **PIPE DIAMETER:** N/A
- **MAXIMUM WATER DEPTH:** 6600 feet working; 8300 feet max.
- **MODE OF INTERVENTION:** Manned Submersible
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive

## ADDITIONAL INFORMATION:

- **Crew:** 2 pilots
- **Life Support:** 250 manhours
- **Payload:** 1500 lbs
- **Lift Capacity:** 800 lbs
- **Features:** 2 thrusters; 1 heavy duty claw; 1 x 6 function manipulator; 3 cameras; 3 X 1000 W lights; 3 viewports; gyro; depth gauge; sonar; directional transducer; water jet
- **Operator:** International Underwater Contractors
- **Supplier:** International Underwater Contractors

**REFERENCE:** Section 5.3.2

MODES OF INTERVENTION		KEY COMPARISON PARAMETERS					VESSEL REQUIREMENTS	SUPPORT EQUIPMENT REQUIREMENTS	ADDITIONAL DATA AND COMMENTS	DATA SHEET REF.
		WATER DEPTH (FEET)	AVAILABILITY	DEVELOPMENT STATUS	EXPERIENCE	BOTTOM TIME (MINUTES)				
DIVER	SATURATION	1000 WORKING 1500 MAXIMUM	WORLDWIDE	OPERATIONAL	EXTENSIVE TO 650 FEET, LIMITED BEYOND	240	<ul style="list-style-type: none"> <li>• DECK SPACE</li> <li>• CRANE AND/OR WINCH</li> <li>• STATION KEEPING ABILITY</li> <li>• LIVING QUARTERS</li> </ul>	<ul style="list-style-type: none"> <li>• HAND HELD TOOLS</li> <li>• GAS SUPPLY</li> <li>• SATURATION SPREAD</li> <li>• COMMUNICATION SYSTEM</li> </ul>	<ul style="list-style-type: none"> <li>• RESEARCH HAS BEEN DIRECTED TOWARDS SAFETY, INCREASED DEPTH AND BOTTOM TIME BY EXPERIMENTS WITH NEW GAS MIXTURES</li> <li>• DIVING IS VERY RELIABLE</li> <li>• EXPENSE BECOMES PROHIBITIVE WITH DEPTH</li> </ul>	5.2-1
	WORK VEHICLE	25,000	WORLDWIDE	OPERATIONAL	EXTENSIVE TO 3500 FEET, LIMITED BEYOND	EXTENDED	<ul style="list-style-type: none"> <li>• CRANE AND/OR WINCH</li> <li>• STATION KEEPING ABILITY</li> <li>• ELECTRICAL POWER SUPPLY</li> </ul>	<ul style="list-style-type: none"> <li>• SPECIALIZED TOOLS</li> <li>• UMBILICAL REEL</li> <li>• CONTROL ROOM</li> <li>• BACK-UP SYSTEM</li> </ul>	<ul style="list-style-type: none"> <li>• USED FOR PIPE CUTTING/ GRINDING, CABLE CUTTING, OPERATIONAL OF HYDRAULIC TOOLS, WATER JETTING, DAMAGE LOCATION/ASSESSMENT, FLANGE/VALVE SEAL REPAIR, ANODE REPAIR/REPLACEMENT, RIG/PLATFORM SUPPORT</li> </ul>	5.3-1 THRU 5.3-13
ROV	INSPECTION VEHICLE	6500	WORLDWIDE	OPERATIONAL	EXTENSIVE TO 2500 FEET, LIMITED BEYOND	EXTENDED	<ul style="list-style-type: none"> <li>• DECK SPACE</li> <li>• CRANE AND/OR WINCH</li> <li>• STATION KEEPING ABILITY</li> <li>• ELECTRICAL POWER SUPPLY</li> <li>• LIVING QUARTERS</li> </ul>	<ul style="list-style-type: none"> <li>• SPECIALIZED TOOLS</li> <li>• UMBILICAL REEL</li> <li>• CONTROL ROOM</li> <li>• BACK-UP SYSTEM</li> </ul>	<ul style="list-style-type: none"> <li>• MAY BE FREE SWIMMING</li> <li>• LIFE SUPPORT RANGES FROM 2 TO 5 DAYS</li> <li>• REQUIRES SKILLED PERSONNEL TO OPERATE</li> <li>• USED PRIMARILY FOR INSPECTION OR OBSERVATION CAPACITY, BUT IS EQUIPPED WITH MANIPULATORS TO PERFORM THE SAME WORK AS ROVS</li> </ul>	5.3-14 THRU 5.3-16
	ADS	2300	WORLDWIDE	OPERATIONAL	EXTENSIVE	EXTENDED				5.3-17 AND 5.3-18
MANNED SUBMERSIBLE	DUAL PURPOSE	2600 MANNED 3300 REMOTE	WORLDWIDE	OPERATIONAL	EXTENSIVE	EXTENDED	<ul style="list-style-type: none"> <li>• DECK SPACE</li> <li>• CRANE AND/OR WINCH</li> <li>• STATION KEEPING ABILITY</li> <li>• ELECTRICAL POWER SUPPLY</li> <li>• LIVING QUARTERS</li> </ul>	<ul style="list-style-type: none"> <li>• SPECIALIZED TOOLS</li> <li>• UMBILICAL REEL</li> <li>• CONTROL ROOM</li> <li>• BACK-UP SYSTEM</li> </ul>	<ul style="list-style-type: none"> <li>• MAY BE FREE SWIMMING</li> <li>• LIFE SUPPORT RANGES FROM 2 TO 5 DAYS</li> <li>• REQUIRES SKILLED PERSONNEL TO OPERATE</li> <li>• USED PRIMARILY FOR INSPECTION OR OBSERVATION CAPACITY, BUT IS EQUIPPED WITH MANIPULATORS TO PERFORM THE SAME WORK AS ROVS</li> </ul>	5.3-19 AND 5.3-20
	MULTI-MANNED	6600 WORKING 8300 MAXIMUM	WORLDWIDE	OPERATIONAL	EXTENSIVE	EXTENDED				

TABLE 5.1

MODES OF INTERVENTION

CAT.	SYSTEM	OPERATOR	SUPPLIER	PAYLOAD (LBS)	LIFT CAPACITY (LBS)	MAXIMUM OPERATING CURRENT (KNOTS)	CRUISING SPEED (KNOTS)	MAXIMUM OPERATING DEPTH (FEET)	LIFE SUPPORT (HOURS)	POWER SOURCE	CAPABILITIES AND EQUIPMENT	DATA SHEET REF.
WORK ROV	GEMINI	OCEANEERING	OCEANEERING	400	1500	--	--	5,000	N/A	UMB	1 MANIPULATOR, WORK TOOLS	5.3-1
	HYDRA	OCEANEERING	ISE	200	250	3.0	--	8,200	N/A	UMB	2 MANIPULATORS, WORK TOOLS, TMS	5.3-2
	MAGELLAN 725	EASTPORT	EASTPORT	200	--	2.5	3.0	25,000	N/A	UMB	2 MANIPULATORS, WORK TOOLS, TMS; LONG RANGE SONAR	5.3-3
	PIONEER	SUBSEA	SUBSEA	200	500	--	3.0	6,000	N/A	UMB	2 MANIPULATORS; INSPECTION EQUIPMENT; WORK TOOLS	5.3-4
	RECON IV	IUC	PERRY	250	400	--	3.0	2,300	N/A	UMB	2 MANIPULATORS; WORK TOOLS, TMS; INSPECTION EQUIPMENT	5.3-5
	RIGWORKER R3000	ROCKWATER	OSEL	187	--	2.0	3.0	3,280	N/A	UMB	2 MANIPULATORS; WORK TOOLS; INSPECTION EQUIPMENT; PROFILER	5.3-6
	SCORPIO PLUS	SUBSEA	SUBSEA	200	400	--	2.5	3,000	N/A	UMB	2 MANIPULATORS; WORK TOOLS	5.3-7
	DRAGONFLY	BUE	OSEL	1000	--	2.5	3.0	6,562	N/A	UMB	2 MANIPULATORS; INSPECTION EQUIPMENT	5.3-8
	HYDROBOT 1000	HYDROBOTICS	HYDROBOTICS	25	--	--	3.0	1,500	N/A	UMB	1 ARTICULATOR; INSPECTION EQUIPMENT	5.3-9
	RCV 225c	ROCKWATER	HYDRO PRODUCTS	N/A	N/A	1.0	1.5	1,350	N/A	UMB	INSPECTION EQUIPMENT; TMS; 1 TAG MANIPULATOR	5.3-10
INSPECTION ROV	UFO 350c	ROCKWATER	OSEL	N/A	N/A	1.5	2.0	1,350	N/A	UMB	INSPECTION EQUIPMENT; TMS; LEAK DETECTION SYSTEM	5.3-11
NOTES: UMB - UMBILICAL TMS - TETHER MANAGEMENT SYSTEM ISE - INTERNATIONAL SUBMARINE ENGINEERING IUC - INTERNATIONAL UNDERWATER CONTRACTORS OSEL - OFFSHORE SYSTEMS ENGINEERING LTD.												

TABLE 5.2  
SUBMERSIBLES

CAT.	SYSTEM	OPERATOR	SUPPLIER	PAYLOAD (LBS)	LIFT CAPACITY (LBS)	MAXIMUM OPERATING CURRENT (KNOTS)	CRUISING SPEED (KNOTS)	MAXIMUM OPERATING DEPTH (FEET)	LIFE SUPPORT (HOURS)	POWER SOURCE	CAPABILITIES AND EQUIPMENT	DATA SHEET REF.
COMBIN. ROV	HYSUB 25	EASTPORT	EASTPORT	200	--	3.5	4.0	5,000	N/A	UMB	2 MANIPULATORS; WORK TOOLS; TMS; INSPECTION EQUIPMENT; HOTSTAB UNIT	5.3-12
	SCORPIO 1000	EASTPORT	EASTPORT	100	--	2.5	3.0	3,280	N/A	UMB	2 MANIPULATORS; WORK TOOLS; TMS; INSPECTION EQUIPMENT; HOTSTAB UNIT	5.3-13
	HORNET	OCEANEERING	OSEL	--	--	2.0	1.5	2,300	80	UMB	2 JAW GRIP ARMS; NO LEGS; 1 MANIPULATOR	5.3-14
ADS	NEWT SUIT	UAS	INT'L HARD SUITS	--	--	--	--	1,000	48	UMB/PP	ARTICULATED ARMS AND LEGS; INTER- CHANGEABLE MANIPULATORS; TETHERED OR FREE	5.3-15
	WASP 2A	OCEANEERING	OSEL	--	--	--	--	2,300	72	UMB	2 ARTICULATED ARMS; NO LEGS	5.3-16
	DUP LUS II	SCANDIVE	OSEL	220/440	132	--	2.5	2625/3280	72	UMB	2 MANIPULATORS; 1 GRABBER ARM; SELF MONITORING; MANNED OR REMOTE	5.3-17
DUAL PURPOSE	MANTIS	IUC	OSEL	440	50	--	3.0	2,300	96	PP	2 MANIPULATORS; WORK TOOLS; INSPECTION EQUIPMENT; MANNED OR REMOTE	5.3-18
	OSS 1500	THYSSEN	THYSSEN	40,000	50,000	2.0	8.0	4,921	120	PP	CARGO HOLD WITH CRANE AND 2 MANIPULATORS; WORK TOOLS; INSPECTION EQUIPMENT; DRONE VEHICLE	5.3-19
MULTI- MANNED	PISCES VI	IUC	IUC	1500	800	--	2.0	8,300	125	PP	1 HEAVY CLAW; 1 MANIPULATOR; INSPECTION EQUIPMENT; WORK TOOLS	5.3-20
NOTES: UMB - UMBILICAL PP - POWER PACK TMS - TETHER MANAGEMENT SYSTEM OSEL - OFFSHORE SYSTEMS ENGINEERING, LTD. UAS - UNDERWATER ATMOSPHERIC SYSTEMS IUC - INTERNATIONAL UNDERWATER CONTRACTORS												

TABLE 5.2 (cont.)  
SUBMERSIBLES

## **Chapter Six**

### **DAMAGE LOCATION AND ASSESSMENT**

## Chapter Six

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## Chapter Six

### DAMAGE LOCATION AND ASSESSMENT

#### 6.1

#### INTRODUCTION

The ability to locate pipeline system damage and to gather sufficient information to allow an assessment is dependent on the type and magnitude of the damage as well as the actual method by which it is located. The damage scenarios in this Chapter relate to those discussed in Chapter Four, where damage has been categorized in terms of type, cause and level of severity. For the purposes of this section the damage types are retained for reference but a broader classification is introduced as follows:

- Minor to Intermediate Damage which includes Damage Severity Levels 1 through 4. This form of damage can be due either to progressive deterioration (i.e. corrosion, anode depletion, scour below the pipe) or to accidental effects (i.e. external impacts resulting in dents, gouges or even small leaks). The key feature of this damage is that it does not outwardly affect the operation of the pipeline system. Damage could go unnoticed unless the line is under surveillance for other reasons, such as an inspection program.
- Major Damage which includes Damage Severity Levels 5 and 6. Damage will involve substantial leakage from the system and should therefore be detected as part of day to day operations.

Obviously, there are exceptions to this categorization scheme such as damage occurring during construction with detection during as-built survey and testing stages.

The damage location and assessment techniques discussed in the following sections can be defined as either:

- external or
- internal.

External damage location techniques do not require access to the inside of the pipeline and operate using visual or acoustic location of the damage.

Acoustic location of damage includes seismic techniques and techniques to detect characteristic sounds emitted by flow escaping through the pipewall. Also, techniques are available for locating traces of the pipeline contents in the area surrounding the damage. Visual techniques are normally employed once the area of damage has been identified and a specific description and assessment of the damage is necessary. External techniques can also be used to locate major damage such as suspected wet buckles, ruptures, etc. that can be easily identified by divers or ROVs. The devices used to listen for sounds emitted from wet damage are more appropriate for smaller, less extensive damages such as pinholes, flange leaks, etc. These devices become less effective, however, in cases where the damaged section of pipeline is buried and the emitted sound is impaired by the soil. Hydrocarbon sniffers are capable of locating wet damage by detecting the pipeline contents in the environment in the vicinity of the damage. The sniffers are towed or driven along the pipe much in the same manor as the listening devices. With the exception of platform mounted pressure transducers, which are discussed as an external method, each of these systems requires surface and subsea support to be effective.

Internal damage location devices require access to the inside of a pipeline with entry usually being gained through the use of a pig. Damage is located by the monitoring of characteristics associated with deterioration or a break in the line. As with external devices, surface support may be required for tracking of a pig inside the pipeline.

In order to summarize the external and internal methods discussed in this section, data sheets and matrices are provided in Section 6.4.

## 6.2

### EXTERNAL METHODS

Several methods of external damage location are presented:

- visual techniques;
- acoustic systems;
- fluorimeter type damage locators;
- hydrocarbon sniffer;
- hydrophones; and
- pressure transducers.

Each method is discussed below and in each case the capabilities are presented in terms of the damage types and categories given earlier in this

Chapter and in Chapter Four. The matrix presented in Table 6.1 summarizes the limitations and applicability of each of the techniques listed above.

## 6.2.1 Visual Techniques

### 6.2.1.1 Methods

In addition to application in planned inspection and verification of pipeline system, visual techniques can be used to locate and assess suspected areas of damage.

These visual techniques range from saturation diving to the use of manned submersibles and ROVs. In most cases the divers and submersible vehicles are equipped with a camera for video transmission to the surface vessel.

- Saturation divers perform numerous subsea operations dealing with the inspection and repair of subsea pipelines. Usually, the diver will visually locate damage while walking the line during a post-lay inspection. In the case where a pipeline is in operation and a leak or rupture is suspected in a particular area, the diver may be sent down to assess the extent of the damage and relay his findings to the surface vessel. A diver may also inspect a section of pipeline using hand-held ultrasonic probes or a hand-held potential measuring device to monitor the effectiveness of the cathodic protection system. To be cost effective, saturation divers can only be used to inspect small areas or short pipelines due to the rate of inspection and low visibility. The limitations on water depth are also a consideration. A detailed discussion on diver capabilities and limitations can be found in Chapter Five.
- ROVs have come to the forefront in subsea inspection since the evolution of ROV technology is at a state where most pipeline survey requirements may be catered. These developments have rendered ROVs the most capable of locating and assessing damage. The vehicle is normally controlled from the surface and overcomes the diver duration limitations inherent in manned subsea vehicles.

The control umbilical supplies the ROV with the electrical and hydraulic power required to operate its various systems such as thrusters, lights, video; manipulators, survey instrumentation, etc. Continuous data collection also allows on-line processing to be accomplished.

However, low visibility, high cost and slow inspection rates limit the ROV to small areas and short pipelines. More often than not, the ROV will be used in conjunction with fluorimeters, sniffers or hydrophones. These systems can increase the inspection rate and render the ROV more cost effective. The fluorimeter, sniffer and hydrophone techniques are discussed later in this Chapter.

- Manned submersibles are used by the offshore industry to locate damage in submarine pipeline systems. They carry a self-contained life support system and may be either tethered to the surface vessel by an umbilical cable or free-swimming with independent power supply. Manned submersibles are discussed in detail in Chapter Five.

A manned submersible is considered more effective than divers and has the advantage that it can be equipped with a range of acoustic and visual location equipment such as side-scan sonar, sub-bottom profilers and closed circuit video. Other equipment may be installed such as a unit to measure currents and voltages induced by the cathodic protection system of the pipeline.

The effectiveness of visual damage location techniques employed by submersibles is dependent on the contrast of the object to be inspected relative to its surroundings. In deeper waters, the natural light may be supplemented by artificial light directed onto the pipeline.

The range of a TV camera is normally determined by the signal/noise ratio which affects resolution. In poor visibility, the TV camera allows an inspection range considerably greater than that of the human eye.

#### 6.2.1.2

##### Limitations and Applicability

Visual techniques are applicable only to sizeable external damage which is readily visible. Hence, visual inspection is not appropriate to internal damage, damage to welds or the pipewall which is too small to see or

damage below corrosion and weight coatings. Additional information on the limitations and applicability of visual method is given in Table 6.1.

## 6.2.2 Acoustic Systems

### 6.2.2.1 Method

Acoustic systems operate on the principle of measuring the time elapsed between a transmitted sound signal and the receipt of its echo. The acoustic image generated by the reflected signal reveals pipeline integrity, leaks and major damage along with bottom features such as mud slides, presence of scouring, spans, boulders, wreckage, etc. Suspect areas of the pipeline will require visual inspection to assess the exact nature of the problem or obstruction encountered.

- Side-scan sonar presents an acoustic, slightly distorted, plan of the seabed and pipeline. In a typical system, transmitting and receiving transducers are mounted in a special 'fish' which is towed behind a support vessel at a short distance above the sea bottom. The transducers emit sharply defined fan-like sonic beams directly down and to each side of the tow fish, in a direction perpendicular to the towing track. The reflected signals are recorded on separate channels onboard the support vessel and create an acoustic image (sonogram) of the sea floor to each side and beneath the tow fish.

Side-scan sonar systems may be used for detection of major damage by replacing the contents in the pipeline with high pressure air which escapes through the break in the line. The escaping air bubbles, which will leak at a much higher volumetric flow rate than the contents, should be visible on a side-scan record and will also be easier to detect visually than the contents in order to pinpoint the damage location.

- Sub-bottom profilers operate on the same principle as the side-scan sonar, but use a high energy, low frequency signal capable of penetrating the subsurface layers of the seabed. Buried pipelines should therefore be detected and the amount of cover over the pipeline determined with a reasonable degree of accuracy. However, these systems are not always capable of picking up lines that have sunken into soft muddy beds. In the case of unburied lines, a sub-bottom profiler may be employed to check regions along the route where wet damage of the pipeline may be suspected.

Towed systems in general offer high resolution for detailed sub-bottom analyses associated with the detection of uncovered pipelines. They are also equipped with a heave compensation unit which eliminates the possible degradation of signal caused by variations in fish attitude.

These systems can be useful in locating a wet damaged pipe section which is unburied and has been pulled off the right-of-way. However, the process is slow and costly and is not commonly used for pipelines already in service. Towed systems may be deployed from a surface support vessel or by a submersible.

#### 6.2.2.2 Limitations and Applicability

Acoustic techniques rely on producing images of the pipeline and surrounding seafloor. The systems are applicable to pipewall leaks and component failures which produce bubbles that can be picked up by these systems. The techniques are also applicable to the initial detection of pipeline spanning or excessive scour and locating damage to pipelines which have been dragged away from the right-of-way. Internal damage or dry damages cannot be picked up and are therefore not applicable in this respect. The matrix presented in Table 6.1 summarizes the limitations and applicability of these acoustic techniques.

#### 6.2.3 **Fluorimeter Type Detectors**

##### 6.2.3.1 Method

Certain substances absorb the light when illuminated and remit light of another wavelength. This property is called fluorescence and is displayed by certain types of dyes and more importantly by certain fractions of hydrocarbon fluid. Fluorimeter type detectors use this property to detect high concentrations of dye or hydrocarbon which have been released into the surrounding seawater from a damaged pipeline.

The detector operates by pulsing a very bright light of the order of 100 kW. A silicon detector then measures the amount of light re-emitted through fluorescence. Smart electronics minimize the effects of incident light and reflected light from silt particles; therefore an output of dye or hydrocarbon concentration in the seawater versus time may be produced and relayed to a surface monitoring team. When the fluorimeter is used for the detection of hydrocarbons an ultraviolet source light, which produces the maximum fluorescence, is utilized. However, as the composition of hydrocarbon fluid varies significantly from source to source, it is imperative that tests be run

to ascertain that the hydrocarbon fluid in question contains sufficient fluorescent components to be effectively detected. If there are insufficient naturally occurring fluorescents present, it is possible that a hydrocarbon tracer or a dyed water medium may be added to the fluid to improve sensitivity.

The fluorimeter is usually fitted to an ROV which is maneuvered alongside the pipeline; however, the cost of the ROV and its support could become prohibitive for surveying long lengths of pipeline. Therefore the fitting of a fluorimeter to a towed (non-intelligent) submersible should be considered. This could considerably reduce costs and scanning times.

Conditions of the seabed in deepwater are usually very still, thus for minor leaks at least, fluid is unlikely to be mixed into the surrounding water mass and will be confined to a relatively narrow plume. Larger damage, which will yield a greater degree of dispersion and higher concentration, is not considered to present any problems with regards to detection. Any high fluorescent activity adjacent to the pipe is investigated.

#### 6.2.3.2

##### Limitations and applicability

Fluorimeters apply to leak location and major wet damage. The leaks may originate from a pinhole in the line, a damaged flange seal ring, a leaky subsea valve, fractures, wet buckles, punctures, etc. Often a dye must be injected into the pipeline which is concentrated enough for detection by a fluorimeter translated along the line. The fluorimeter leak locator is accurate to 0.5 feet for small damage but requires that the pipe be unburied. Major damage will disburse the dye over a widespread area causing the degree of accuracy to decrease. Additional information on the limitations and applicability of fluorimeter systems is given in Table 6.1.

#### 6.2.4

##### **Hydrophones**

##### 6.2.4.1

##### Method

Fluid leaking from a damaged pipeline under pressure emits a characteristic sound which may be detected by a suitably sensitized hydrophone.

The usual mode of operation is to translate a hydrophone along the pipeline route using either an ROV or a towed submersible. Surface equipment monitors sounds picked up by the hydrophone and it is thus possible to locate the damaged section. To reduce background noise, frequent motor shutdowns may be needed. However, for major damage this should not present a problem.

#### 6.2.4.2 Limitations and Applicability

Hydrophones which are used to pick up emitted acoustic noise are suited only to the location of small leaks. This includes pinholes, leaking flanges or valves, and the beginnings of cracks or fractures due to corrosion or over-pressure in the line. Major damage does not emit a high pitched sound because the leak is generally slower and therefore is harder to pick up by the hydrophones. However, high pressure air can be introduced into the line which will increase the receivability of the hydrophones. Additional limitations include weight coatings and overburden which tend to muffle the emitted noise and render the hydrophone incapable of detection. Additional information on this system can be found in the matrix given in Table 6.1.

#### 6.2.5 **Pressure Transducers**

##### 6.2.5.1 Method

When wet pipeline damage occurs, a sudden change in operating pressure at the point of the break generates an expansion wave that travels at acoustic velocity through the fluid in the pipeline. Pressure transducers placed at each end of a pipeline can detect such acoustic waves and by measuring the time of arrival of the waves at each transducer an estimation of the damage location may be made.

The sensitivity of this technique is poor and dependent upon the distance between the two transducers. Thus, for long pipelines it is likely that only major damages will be located.

##### 6.2.5.2 Limitations and Applicability

Pressure transducers mounted at each pipe end are limited to locating wet pipeline damage only. However, this technique applies to small leaks as well as major damage for buried and unburied pipelines. The location technique is based on the amount of pressure loss in the line over its length. Naturally, a more accurate reading is produced for shorter lines and major damages but the system can also be used for longer lines to get a rough location of the damage source. The pipeline must also originate and terminate at a platform. The system is not suited to lines which tie-in to trunklines. Refer to the matrix in Table 6.1 for additional information.

#### 6.2.6 **Cathodic Protection Monitoring**

##### 6.2.6.1 Method

The integrity of the pipeline depends, in part, upon the performance of the cathodic protection (CP) system. During visual inspection, it is usually

convenient to incorporate a check of the CP system also. The information gained in this way is valuable since:

- 1) by measuring pipe to sea potentials the level of protection afforded to the pipe and performance of the CP systems can be evaluated; and
- 2) the performance of the corrosion coating can be assessed.

In the event there are sections of the pipeline that are discovered to be inadequately protected, corrective action can be taken (i.e. fitting of additional anode material).

- Pipe-to-Sea Potential (PSP) inspections are made when a high impedance voltmeter is connected to a reference electrode. If defects exist within the pipeline coating, more electrical current will flow through the sea to these areas than to the surrounding well coated areas. This will result in a detectable variation in potential around the defect.
- Diver contact is made with the pipeline using a hand-held, spiked probe. The probe either contains a high resistance voltmeter or is connected to a voltmeter carried in a submersible or surface vessel.

This method is only suitable for relatively small lengths of pipeline and is restricted by the depth at which divers can work efficiently and economically.

- Trailing wire towed electrode method employs a direct connection to the pipeline using a fine, insulated 'lite wire'. The wire is connected to a high resistance voltmeter on a surface vessel which is in turn connected to a reference electrode housed in a towed 'fish'. The towed electrode is directed along the pipeline route as close as possible to the pipeline. Overall levels of protection will be indicated. This method is quick since the vessel is travelling at several knots. Difficulties may be experienced on long lines since each few miles re-connection to the pipeline will be necessary. The system is also applicable for buried lines, provided that electrical contact can be maintained.

- Trailing wire close electrode is a development of the towed electrode system. The method of continuous contact with a 'lite-wire' is utilized, but instead of a towed electrode, a manned submersible is used with the electrode mounted on the front. Because of continuous electrical contact, actual PSP measurements are recorded and, for unburied lines, the electrode can be maintained in close proximity to the pipeline for determining local variations in PSP.
- Field intensity measurements consist of a variety of systems. Usually potential difference in the sea is measured between two half cells mounted on an ROV or submersible close to the pipe. Depending upon the plane measurement, either the radial field strength or longitudinal field strength is determined. Some systems measure current in the sea using magnetic cores. From the potential difference or current measurements obtained, current densities can be computed and by modelling or numerical analysis, these can be interpreted to provide PSP values. Actual PSP measurements are usually made at interval anodes and other convenient points to provide a degree of calibration.
- Remote electrodes comprise a pair of electrodes mounted on a submersible and a third remote electrode suspended approximately 175 feet away on the submersible's umbilical. These connected electrodes measure actual PSP at half mile intervals. These values, positive or negative, are added to the previous actual PSP reading, thus providing interpolated values along the length of the pipeline. By measuring the potential difference in the sea between the pair of electrodes on the submersible, an estimate can be made of the current density at that location. This is used to estimate current demand at large areas of damage and current output at anodes.

#### 6.2.6.2 Limitations and Applicability

Cathodic protection monitoring methods are only applicable to anode damage or depletion and external corrosion detection. The methods discussed above are limited by pipeline overburden, diver/ROV capabilities and pipeline length. For additional information and references see Table 6.1.

### 6.3 INTERNAL METHODS

Several methods of internal damage location and assessment are presented:

- buckle detectors;
- geometry pigs;
- pigs fitted with acoustic pinger;
- ultrasonic detection pigs; and
- intelligent pigs.

Each method is discussed in detail below. The limitations and applicabilities specific to each manufacturer's system, pertaining to these methods, can be found in the matrix presented in Table 6.2.

#### 6.3.1 Buckle Detectors

Buckle detectors are the simplest form of damage location and are normally used during the installation stage of the pipeline. The tool is made up of two plates that are attached to a frame on the laybarge rollers. The plates are designed to be circular and just smaller than the minimum allowable inside diameter of the pipe. The buckle detector may be installed inside the pipe just beyond the sagbend during pipelay. It is attached to a tension line that runs up through the pipe to the pipelay vessel. The line is closely monitored for abnormal tension and the detector is retrieved periodically to check for buckled pipe damage.

If the buckle detector is damaged, pipelay is halted and divers or ROVs are sent down to inspect the pipeline at the overbend and sagbend regions to confirm and assess the damage. This system is not always used because it can slow down the installation process, become lost in the line or jammed due to debris build-up. Normally, the operator will decide whether a buckle detector is warranted for a specific job or not.

#### 6.3.2 Geometry Pigs

Internal geometry pigs gauge the general configuration of the pipeline and provide information on ovality, buckles, gouges, dents and wrinkles. These pigs are often incorporated in pre-pigging programs along with mechanical and magnetic cleaning pigs to prepare the pipeline for hydrotesting. Geometry pigs are usually propelled by water, although air is sometimes used.

The pipeline damage must be sufficient in magnitude to stop the geometry pig. If it cannot be retrieved, and additional pig is introduced into the pipeline which is equipped with an acoustic pinger. The pinger can be located by a small vessel equipped with a tracking device. Divers or ROVs can then be sent down to assess the problem. The use of acoustics to track a pig is discussed in the following section. Data sheets on the geometry pigs can be found following this section.

### **6.3.3**

#### **Pigs Fitted with Acoustic Pinger**

This method of damage location has been used successfully in the North Sea and other areas. A separation type pig is fitted with a tracking device, usually an acoustic pinger, which enables the position of the pig within the pipeline to be ascertained. The pig is inserted into the pipeline through the pig launcher and driven down the pipeline. As long as the valve at the pig receiver is closed, then the only route of escape for the contents in the pipeline is through the break in the line. Thus, once the pig reaches a leak, it will stop in that vicinity. A diver or ROV may then locate the pig within the damaged area of pipeline. The accuracy of the location method depends on the pipeline contents. With incompressible fluid (i.e. oil) ahead of the pig, the stopping point will be close to the leak. Less accuracy will be achieved with a gas line.

This method is straightforward, does not involve any complicated equipment and is, therefore, considered to be reliable. If problems do arise, they are most likely concerned with the tracking of the pig. Although cases of lost pigs have occurred tracking the pig from its launch should minimize this occurrence. The maximum velocity of the pig is determined by the rate of leakage and, therefore, for small leaks this method could be time consuming. Suitable pig tracking systems are presented in Table 6.2.

### **6.3.4**

#### **Ultrasonic Detection Pigs**

This system employs a pig-mounted ultrasonic sensor which resolves the discrete band of frequencies emitted by flow conditions at a break in the line. The pig is pumped through the pipeline in the normal manner, while sound signals are detected and recorded within the pig. The recordings are processed upon receipt of the pig at the other end of the pipeline in order to determine the location of the damage with reference to known points on the pipeline. These known points along the pipeline route can be provided by fixing acoustic markers to the pipewall.

If the damage to the line is major, the pig will be restricted from passing to the other pipe end. To prevent losing the pig, in this case, a pinger may be attached to the pig. This way, the pig's location can be monitored during its run. A sensitivity range of 0.2 to 0.4 feet<sup>3</sup>/hour is the limiting detectable leak rate due to deterioration. Below this level the system would be unable to function.

Background noises due to pipeline equipment, the carriage, and the fluid flow can be a problem with this type of equipment, but may be overcome by selective filtering of the signals and measurement of the background noise in the pipeline. The sensitivity of the signal is affected by the pipeline contents and the cleanliness of the line.

### 6.3.5 Intelligent Pigs

Intelligent pigs are capable of producing information regarding some or all of the following aspects of internal and external pipeline damage location:

- temperature - pressure recording;
- photographic inspection;
- bend location and measurement;
- pitting corrosion;
- delamination type corrosion;
- mechanical damage;
- gouges, dents and wrinkles;
- hardspots;
- hydrogen busters; and
- circumferential cracks.

Most intelligent pigs gather information by the magnetic flux detection method. The method measures the volume loss of the pipewall to detect damage and becomes less effective with increasing wall thickness. These pigs are more useful if major damage is suspected.

Several of these pigs have been developed to provide either visual inspection of the inner surface of the pipeline or to detect and measure specific features such as deterioration of the pipeline due to longitudinal cracking of the pipewall. Others incorporate systems to verify the geometry of the pipeline. These pigs are more useful if major damage is suspected. Details are provided in Table 6.2.

## **6.4 DATA SHEETS AND MATRICES**

This section contains data sheets and matrices which include pertinent information on specific techniques that fall under the category of damage location and assessment. The data sheets are specific to each tool while the matrices, Tables 6.1 and 6.2, list several techniques by category, manufacturer, and limitations and applicabilities. The information which is provided represents the basic parameters necessary to formulate a decision on the type of technique which best suits a specific damage location and assessment requirement.

# DATA SHEET

**REFERENCE:** 6.2-1

**AREA:** Damage Location & Assessment

**CATEGORY:** External Methods

**TECHNIQUE:** Visual

**DESCRIPTION:** Visually locates damaged area and assesses a means of repair by naked eye or camera

## KEY PARAMETERS:

- **PIPE DIAMETER:** N/A
- **MAXIMUM WATER DEPTH:** Dependent on Mode of Intervention
- **MODE OF INTERVENTION:** Diver/ROV/Submersible
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive

## ADDITIONAL INFORMATION:

- **Capabilities:** Detect/measure any type of leak or damage of an unburied pipeline
- **Limitations:** Costly over a long distance due to inspection rate and visibility
- **Required Equipment:** Support vessel; subsea TV monitoring system

**REFERENCE:** Section 6.2.1

# DATA SHEET

**REFERENCE:** 6.2-2

**AREA:** Damage Location & Assessment

**CATEGORY:** External Methods

**TECHNIQUE:** Acoustic Systems

**DESCRIPTION:** Locates damage by transmitting a sound signal and measuring its echo with respect to a known position along the pipeline

## KEY PARAMETERS:

- **PIPE DIAMETER:** N/A
- **MAXIMUM WATER DEPTH:** Dependent on Mode of Intervention
- **MODE OF INTERVENTION:** ROV/Submersible/Fish
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive

## ADDITIONAL INFORMATION:

- **Types of Systems:**
  - 1) Side-scan sonar emits sonic beams to produce an acoustic image of the seafloor
  - 2) Sub-bottom profiler emits a high energy signal which penetrates to seafloor to show buried pipelines and subsurface layers
- **Capabilities:** Detects/measures large or small leaks of unburied or buried pipelines (depending on the system), pipeline spanning, scour, signs of foreign objects on line
- **Limitations:** An air working medium is sometimes needed by side-scan sonars to enhance leak image; sub-bottom profilers may not detect pipelines sunken into soft muds
- **Required Equipment:** Support vessel with monitoring equipment and control room for ROV/Submersible
- **Suppliers:** Sachse Engineering Associates - "SEA SEARCH"  
Klein Associates - "HYDROSCAN"

**REFERENCE:** Section 6.2.2

# DATA SHEET

**REFERENCE:** 6.2-3

**AREA:** Damage Location & Assessment

**CATEGORY:** External Methods

**TECHNIQUE:** Fluorimeter Type Detectors

**DESCRIPTION:** Detects escaping fluorescent dyes which have been injected into the pipeline

## KEY PARAMETERS:

- PIPE DIAMETER: N/A
- MAXIMUM WATER DEPTH: 1300 feet
- MODE OF INTERVENTION: Diver/ROV/Fish
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Extensive

## ADDITIONAL INFORMATION:

- Capabilities: Detects wet damage of unburied pipeline
- Limitations: Accuracy depends on size of leak or damage
- Required Equipment: Fluorometer which can be hand-held by a diver or attached to a submersible; support vessel

# DATA SHEET

**REFERENCE:** 6.2-4

**AREA:** Damage Location & Assessment

**CATEGORY:** External Methods

**TECHNIQUE:** Hydrophones

**DESCRIPTION:** Detects the high pressure sound emitted by a pipeline leak

## KEY PARAMETERS:

- **PIPE DIAMETER:** N/A
- **MAXIMUM WATER DEPTH:** Dependent on Mode of Intervention
- **MODE OF INTERVENTION:** ROV/Submersible
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive

## ADDITIONAL INFORMATION:

- **Capabilities:** Detection of small leaks and major wet damage if air is injected into the pipeline
- **Limitations:** Support vessel noise; background noise in shallow water; weight coating, and overburden which muffle sound
- **Required Equipment:** Hydrophone; umbilical; propulsion unit; onboard receiver; support vessel
- **Suppliers:** Helle Engineering  
Benthos

**REFERENCE:** Section 6.2.5

# DATA SHEET

**REFERENCE:** 6.2-5

**AREA:** Damage Location & Assessment

**CATEGORY:** External Methods

**TECHNIQUE:** Pressure Transducers

**DESCRIPTION:** Locates damage by measurement of the time it takes a shock wave to arrive at transducers at each end of the pipeline when the operating pressure fluctuates due to wet damage

## KEY PARAMETERS:

- PIPE DIAMETER: N/A
- MAXIMUM WATER DEPTH: N/A
- MODE OF INTERVENTION: Pipeline Pressure
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Limited

## ADDITIONAL INFORMATION:

- Capabilities: Location of major wet damage to buried or unburied pipelines
- Limitations: Accuracy is lost with increasing line length; small leaks are hard to detect even on short lines
- Required Equipment: 2 pressure transducers; above water stations at each end of pipeline
- Suppliers: Acoustic Systems

**REFERENCE:** Section 6.2.6

# DATA SHEET

REFERENCE: 6.2-6

AREA: Damage Location & Assessment

CATEGORY: External Methods

TECHNIQUE: Cathodic Protection Monitoring

DESCRIPTION: Surveys pipeline for anode depletion or corrosion damage

## KEY PARAMETERS:

- PIPE DIAMETER: N/A
- MAXIMUM WATER DEPTH: Dependent on Mode of Intervention
- MODE OF INTERVENTION: Diver/ROV/Submersible
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Extensive

## ADDITIONAL INFORMATION:

- Types of Systems:
  - 1) Diver Contact
  - 2) Trailing Wire, Close or Towed
  - 3) Field Intensity Measurement
  - 4) Remote Electrodes
- Capabilities: Detects anode damage/depletion and measures performance of system of unburied pipeline
- Required Equipment: Support vessel; ancillary systems depending on devise used

REFERENCE: Section 6.2.7

# DATA SHEET

**REFERENCE:** 6.3-1

**AREA:** Damage Location & Assessment

**CATEGORY:** Internal Methods

**TECHNIQUE:** Buckle Detectors

**DESCRIPTION:** Verify pipeline internal geometry during pipelay

## KEY PARAMETERS:

- **PIPE DIAMETER:** N/A
- **MAXIMUM WATER DEPTH:** N/A
- **MODE OF INTERVENTION:** Gauging Plate
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive

## ADDITIONAL INFORMATION:

- **Capabilities:** Measures ovality of pipe as it is laid
- **Minimum Bend Radius:** Sagbend will govern
- **Required Equipment:** Cable, frame on rollers; 2 gauging plates; tension gauge
- **Other:** These systems are built on the barge during tow-out for each job, they are not manufactured; device may become lost in the line or jammed by debris
- **Supplier/Operator:** Installation Contractor

**REFERENCE:** Section 6.3.1

# DATA SHEET

**REFERENCE:** 6.3-2

**AREA:** Damage Location & Assessment

**CATEGORY:** Internal Methods

**SYSTEM:** Cal-Pig

**FUNCTION:** Evaluates internal geometry

## KEY PARAMETERS:

- PIPE DIAMETER: 6" and greater
- MAXIMUM WATER DEPTH: N/A
- MODE OF INTERVENTION: Mechanical Sensor
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Extensive

## ADDITIONAL INFORMATION:

- Length: Approximately 1.8 x OD
- Min. Bend Radius: 3R (1.5R optional)
- Operating Pressure: 1450 psi (2900 psi optional)
- Inspection Rate: 5.6 ft/sec max.
- Running Time: 1000 hrs. max.
- Capabilities: Changes in pipe diameter are measured by a ring of sensing fingers on the trailing cup; data is recorded on an onboard chart
- Supplier: Piptronix

**REFERENCE:** Section 6.3.2

# DATA SHEET

**REFERENCE:** 6.3-3

**AREA:** Damage Location & Assessment

**CATEGORY:** Internal Methods

**SYSTEM:** EGP (Electronic Geometry Pig)

**FUNCTION:** Evaluates internal geometry

## KEY PARAMETERS:

- **PIPE DIAMETER:** 6" to 48"
- **MAXIMUM WATER DEPTH:** N/A
- **MODE OF INTERVENTION:** Electric field sensor
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Limited

## ADDITIONAL INFORMATION:

- **Length:** Approximately 2.0 to 6.6 x OD
- **Min. Bend Radius:** 1.5R to 3R
- **Operating Pressure:** 2900 psi; 3300 psi max.
- **Inspection Rate:** 16.4 to 19.7 ft/sec max.
- **Running Time:** 50 to 100 hrs. max.
- **Capabilities:** Wall thickness changes, fittings, field and hot bends, and welds are identified by the "touchless" sensors; data recorded by onboard solid-state memory; indicates areas of general internal corrosion
- **Other:** May be used as dewatering and caliper pig; has sleep mode to keep system on-line for up to 3 months
- **Supplier:** HROS USA

**REFERENCE:** Section 6.3.2

# DATA SHEET

**REFERENCE:** 6.3-4

**AREA:** Damage Location & Assessment

**CATEGORY:** Internal Methods

**SYSTEM:** Gauging Pig

**FUNCTION:** Removes or locates obstructions in new pipelines

## KEY PARAMETERS:

- PIPE DIAMETER: 2" to 36"
- MAXIMUM WATER DEPTH: N/A
- MODE OF INTERVENTION: Gauging flange
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Extensive

## ADDITIONAL INFORMATION:

- Length: 5" to 42"
- Min. Bend Radius: 1.5R
- Inspection Rate: 3 to 5 ft/sec
- Capabilities: Cups and gauging flanges force through any obstruction in the line to insure clear passage of cleaning pigs
- Other: Pipewall can be damaged when guaging flanges encounter a reduction in pipe diameter
- Supplier: T.D. Williamson, Inc.

**REFERENCE:** Section 6.3.2

# DATA SHEET

**REFERENCE:** 6.3-5

**AREA:** Damage Location & Assessment

**CATEGORY:** Internal Methods

**SYSTEM:** Gauging/Commissioning Pig

**FUNCTION:** Removes or locates obstructions and verifies roundness of new pipelines

## KEY PARAMETERS:

- PIPE DIAMETER: 1" to 48"
- MAXIMUM WATER DEPTH: N/A
- MODE OF INTERVENTION: Gauging Plate
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Extensive

## ADDITIONAL INFORMATION:

- Length: 49" to 575"
- Min. Bend Radius: 1.5R to 3R
- Inspection Rate: Unknown
- Capabilities: Cups and gauging plate force through any obstruction in the line, prove pipe roundness and identify excessive weld penetration; can transverse full bore ball and conduct valves and barred tees
- Other: Pipewall can be damaged when gauging plate encounters a reduction in pipe diameter
- Supplier: International Pipeline Products

**REFERENCE:** Section 6.3.2

# DATA SHEET

**REFERENCE:** 6.3-6

**AREA:** Damage Location & Assessment

**CATEGORY:** Internal Methods

**SYSTEM:** KALIPER

**FUNCTION:** Evaluates internal geometry

## KEY PARAMETERS:

- PIPE DIAMETER: 8" to 60"
- MAXIMUM WATER DEPTH: N/A
- MODE OF INTERVENTION: Electronic Kaliper system
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational (2nd generation)
- EXPERIENCE: Extensive

## ADDITIONAL INFORMATION:

- Length: 28" to 86"
- Weight: 37 to 900 lbs
- Min. Bend Radius: 3R - 8"; 1.5R all other sizes
- Operating Pressure: 2200 psi
- Inspection Rate: 2.9 to 44 ft/sec
- Capabilities: Dents, wrinkles, buckles, out-of-roundness, flat spots, partially closed valves, bends and pipe reductions are measured by a ring of mechanical sensors within the trailing cup; onboard solid-state memory transfers data to portable computer
- Supplier: T.D. Williamson, Inc.

**REFERENCE:** Section 6.3.2

# DATA SHEET

REFERENCE: 6.3-7

AREA: Damage Location & Assessment

CATEGORY: Internal Methods

SYSTEM: Pig Pinger

FUNCTION: Tracks and locates pig

## KEY PARAMETERS:

- PIPE DIAMETER: 1" and greater
- MAXIMUM WATER DEPTH: 2,000 to 15,000 feet
- MODE OF INTERVENTION: Acoustic pinger
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Extensive

## ADDITIONAL INFORMATION:

- Length: 7" to 16"
- Weight: 1.3 to 17 lbs
- Min. Bend Radius: Unknown
- Battery Life: 12 to 3600 hrs. (varies by model, acoustic output, pulse width, and repetition rate)
- Capabilities: 8 models available; range up to 7 nautical miles; frequency, pulse width and repetition rate are easily adjusted
- Required Equipment: Directional antenna; pinger receiver (diver/ROV/vessel operated)
- Supplier: Helle Engineering

REFERENCE: Section 6.3.3

# DATA SHEET

REFERENCE: 6.3-8

AREA: Damage Location & Assessment

CATEGORY: Internal Methods

SYSTEM: FLAWSONIC

FUNCTION: Identifies and measures pipewall faults

## KEY PARAMETERS:

- PIPE DIAMETER: 8" to 30"
- MAXIMUM WATER DEPTH: N/A
- MODE OF INTERVENTION: Ultrasonics
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Limited

## ADDITIONAL INFORMATION:

- Length: 88" to 100"
- Weight: 185 to 1900 lbs
- Min. Bend Radius: 1.5R to 6R
- Operating Pressure: 1500 to 2000 psi
- Inspection Rate: 14.7 ft/sec max.
- Battery Life: 50 to 90 hours
- Capabilities: External/internal corrosion and pipe lamination detected using ultrasonics; only cups and odometer contact pipewall; solid-state memory; self-calibrating; data analyzed by software FLAWGRAPHIC
- Supplier: TDW Pipeline Surveys

REFERENCE: Section 6.3.4

# DATA SHEET

**REFERENCE:** 6.3-9

**AREA:** Damage Location & Assessment

**CATEGORY:** Internal Methods

**SYSTEM:** Flexi-PIT 50000 (Pipeline Inspection Tool)

**FUNCTION:** Used for inspection tasks requiring large data flows such as crack detection

## KEY PARAMETERS:

- **PIPE DIAMETER:** Unknown
- **MAXIMUM WATER DEPTH:** N/A
- **MODE OF INTERVENTION:** Ultrasonics
- **AVAILABILITY:** None
- **DEVELOPMENT STATUS:** Unknown
- **EXPERIENCE:** None

## ADDITIONAL INFORMATION:

- **Features:** Pig is launched and operated from an open end pipe and pulled through the line by a disposable glass fiber wire which provides the optical link; glass fiber allows storage of data for up to 165,000 feet of inspected line
- **Supplier:** Rontgen Technische Dienst

**REFERENCE:** Section 6.3.4

# DATA SHEET

**REFERENCE:** 6.3-10

**AREA:** Damage Location & Assessment

**CATEGORY:** Internal Method

**SYSTEM:** MLD (Pipeline Leak Detector)

**FUNCTION:** Detects small scale wet damage

## KEY PARAMETERS:

- PIPE DIAMETER: 8" to 40"
- MAXIMUM WATER DEPTH: N/A
- MODE OF INTERVENTION: Ultrasonics
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Limited

## ADDITIONAL INFORMATION:

- Min. Bend Radius: 1.5R
- Operating Pressure: 2900 psi max.
- Inspection Rate: 5.6 ft/sec max.
- Battery Life: 200 hrs. min.
- Capabilities: Detects and measures the characteristic effluent sound emitted by the leak with a hydrophone; signals are analyzed, filtered and amplified by the unit
- Supplier: Maihak AG

**REFERENCE:** 6.3.4

# DATA SHEET

REFERENCE: 6.3-11

AREA: Damage Location & Assessment

CATEGORY: Internal Methods

SYSTEM: PIT 6000 (Pipeline Inspection Tool)

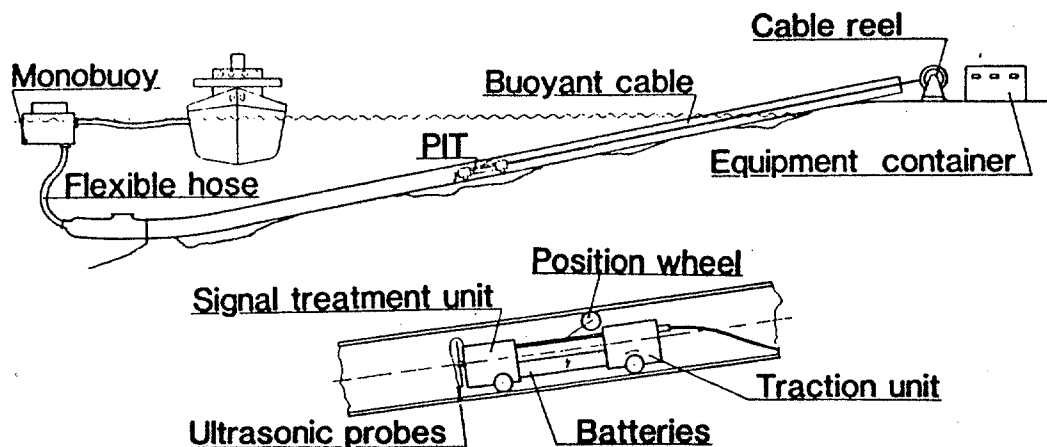
FUNCTION: Identifies and measures pipewall faults

## KEY PARAMETERS:

- PIPE DIAMETER: 16" and up
- MAXIMUM WATER DEPTH: N/A
- MODE OF INTERVENTION: Ultrasonics
- AVAILABILITY: None
- DEVELOPMENT STATUS: Prototype
- EXPERIENCE: Laboratory Testing

## ADDITIONAL INFORMATION:

- Features: Pig is launched and operated from an open end pipe and pulled through the line by a glass fiber wire which also transmits the signal; data gathered from 36 probes for instant review and storage on tapes
- Supplier: Rontgen Technische Dienst



REFERENCE: Section 6.3.4

# DATA SHEET

**REFERENCE:** 6.3-12

**AREA:** Damage Location & Assessment

**CATEGORY:** Internal Methods

**SYSTEM:** Ultrasonic Tool

**FUNCTION:** Identifies and measures pipewall defaults

## KEY PARAMETERS:

- PIPE DIAMETER: 16" to 48"
- MAXIMUM WATER DEPTH: Unknown
- MODE OF INTERVENTION: Ultrasonics
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Limited

## ADDITIONAL INFORMATION:

- Length: 118" to 157"
- Weight: 2400 to 6000 lbs
- Min. Bend Radius: 3R (1.5R optional)
- Operating Pressure: 1450 psi
- Inspection Rate: 1.6 to 3.3 ft/sec
- Battery Life: 60 hrs. max.
- Capabilities: External/internal corrosion and welds surveyed by ultrasonics; only cups and odometer touch pipewall; data recorded on onboard tapes and transferred to computer for analysis
- Supplier: NKK America

**REFERENCE:** Section 6.3.4

# DATA SHEET

**REFERENCE:** 6.3-13

**AREA:** Damage Location & Assessment

**CATEGORY:** Internal Methods

**SYSTEM:** CDP (Corrosion Detection Pig)

**FUNCTION:** Measures internal and external metal loss

## KEY PARAMETERS:

- PIPE DIAMETER: 6" to 48"
- MAXIMUM WATER DEPTH: N/A
- MODE OF INTERVENTION: Magnets
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Extensive

## ADDITIONAL INFORMATION:

- Min. Bend Radius: 1.5R to 5R
- Operating Pressure: 2900 psi
- Inspection Rate: 3.2 to 6.5 ft/sec
- Running Time: 30 to 250 hrs. max.
- Capabilities: Measures corrosion and some pipewall defects by the magnetic flux leakage method; data stored by onboard solid-state memory or digital tape recorders
- Other: 0.366" to 0.945" wall thickness max.
- Operator: HROS USA
- Supplier: HROS USA

**REFERENCE:** Section 6.3.5

# DATA SHEET

**REFERENCE:** 6.3-14

**AREA:** Damage Location & Assessment

**CATEGORY:** Internal Methods

**SYSTEM:** Linalog 360 Corrosion Pit Tool

**FUNCTION:** Locates and evaluates external/internal corrosion, mechanical damage and mill defects

## KEY PARAMETERS:

- PIPE DIAMETER: 4" to 48"
- MAXIMUM WATER DEPTH: N/A
- MODE OF INTERVENTION: Magnets
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Extensive

## ADDITIONAL INFORMATION:

- Length: 98" to 176"
- Weight: 180 to 14,000 lbs
- Min. Bend Radius: Varies case-to-case
- Operating Pressure: 390 to 3000 psi
- Inspection Rate: 1.6 to 11.5 ft/sec
- Running Time: 15 to 120 hrs. max.
- Capabilities: Detects corrosion and pipewall defects by the magnetic flux leakage method; data stored on onboard magnetic tape recorder; body articulated in 3 to 5 sections to negotiate bends
- Other: 0.125" to 1.000" wall thickness max.
- Supplier: Tuboscope Linalog

**REFERENCE:** Section 6.3.5

# DATA SHEET

**REFERENCE:** 6.3-15

**AREA:** Damage Location & Assessment

**CATEGORY:** Internal Methods

**SYSTEM:** On Line Inspection

**FUNCTION:** Detects external/internal corrosion

## KEY PARAMETERS:

- **PIPE DIAMETER:** 8" to 42"
- **MAXIMUM WATER DEPTH:** N/A
- **MODE OF INTERVENTION:** Magnetics
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive

## ADDITIONAL INFORMATION:

- **Min. Bend Radius:** 1.5R
- **Operating Pressure:** 100 to 1015 psi
- **Inspection Rate:** 2.6 to 13 ft/sec max.
- **Capabilities:** Measures corrosion and some pipewall defects using the magnetic flux leakage method; data is stored digitally for later retrieval and interpretation
- **Other:** Line must be pigged by a geometry pig, flexible cup pig and magnetic cleaning pig before run of the tool
- **Supplier:** British Gas

**REFERENCE:** Section 6.3.5

# DATA SHEET

REFERENCE: 6.3-16

CATEGORY: Internal Methods

AREA: Damage Location & Assessment

SYSTEM: Burial and Coating Inspection System

FUNCTION: Pig surveys external condition of pipeline

## KEY PARAMETERS:

- PIPE DIAMETER: 36"
- MAXIMUM WATER DEPTH: N/A
- MODE OF INTERVENTION: Neutron Interrogation
- AVAILABILITY: None
- DEVELOPMENT STATUS: Unknown
- EXPERIENCE: Test

## ADDITIONAL INFORMATION:

- Capabilities: Measures weight coating damage, loss of overburden and spanning instances; data collected on digital record for later retrieval and interpretation
- Other: System not affected by weather conditions or seafloor visibility; reduces frequency of external survey; can map seafloor or check modes
- Supplier: British Gas

REFERENCE: Section 6.3.5

METHOD	TYPE OF DAMAGE ASSESSED	KEY COMPARISON PARAMETERS					ADDITIONAL DATA AND COMMENTS	DATA SHEET REF.
		WATER DEPTH (FEET)	MODE OF INTERVENTION	AVAILABILITY	DEVELOPMENT STATUS	EXPERIENCE		
VISUAL	DIVER	1500	DIVER	WORLDWIDE	OPERATIONAL	EXTENSIVE TO 750 FEET	SLOW RATE; VISIBILITY DEPENDENT; LIMITED TO UNBURIED LINES; BACK-UP REQUIRED; COSTLY	6.2-1
	ROV	20,000	ROV	WORLDWIDE	OPERATIONAL	EXTENSIVE TO 2000 FEET	SLOW RATE; VISIBILITY DEPENDENT; LIMITED TO UNBURIED LINES; COSTLY	
	MANNEED SUBMERSIBLE	8300	SUBMERSIBLE	WORLDWIDE	OPERATIONAL	LIMITED	SLOW RATE; VISIBILITY DEPENDENT; LIMITED TO UNBURIED LINES; MOST EFFECTIVE FOR DEEP WATER; BACK-UP REQUIRED; COSTLY	
	SIDE-SCAN SONAR	DEPENDENT ON MODE	ROV/FISH/SUBMERSIBLE	WORLDWIDE	OPERATIONAL	EXTENSIVE	SLOW RATE; LIMITED TO UNBURIED LINES; BENEFICIAL TO INTRODUCE AIR INTO THE LINE	6.2-2
ACOUSTIC	SUB-BOTTOM PROFILER	DEPENDENT ON MODE	ROV/FISH/SUBMERSIBLE	WORLDWIDE	OPERATIONAL	EXTENSIVE	SLOW RATE; LIMITED TO BURIED LINES; DETECTS NEW POSITION OF A SHIFTED LINE; SOFT MUD DISTORTS IMAGE	6.2-3
	FLUORIMETER LEAK DETECTOR	1300	DIVER/ROV/FISH	WORLDWIDE	OPERATIONAL	EXTENSIVE	LIMITED TO UNBURIED LINES; ACCURATE TO 0.5 FT FROM LEAK; MAY REQUIRE WORKING FLUID OR DYE; MORE ACCURATE ON SLOW LEAKS	6.2-4
	HYDROPHONE	DEPENDENT ON MODE	ROV/SUBMERSIBLE	WORLDWIDE	OPERATIONAL	EXTENSIVE	BACKGROUND NOISE; OVERBURDEN, AND COATINGS MUFFLE SIGNAL; BENEFICIAL TO INTRODUCE AIR INTO THE LINE	6.2-5
	PRESSURE TRANSDUCER	UNLIMITED	PIPELINE PRESSURE	WORLDWIDE	OPERATIONAL	LIMITED	ABOVE WATER STATION AND TRANSDUCER NEEDED AT EACH END; LIMITED TO SHORT LINES EXCEPT FOR MAJOR DAMAGE	6.2-6
	CATHODIC PROTECTION MONITORING	DEPENDENT ON MODE	DIVER/ROV/SUBMERSIBLE	WORLDWIDE	OPERATIONAL	EXTENSIVE	LIMITED TO CATHODIC PROTECTION SYSTEM	

EXTERNAL METHODS OF  
DAMAGE LOCATION AND ASSESSMENT

KEY COMPARISON PARAMETERS														DATA SHEET REF.
SYSTEM	SUPPLIER	PIPE DIAMETER (IN.)	WATER DEPTH (FEET)	MODE OF INTERVENTION	AVAILABILITY	DEVELOPMENT STATUS	EXPERIENCE	PT CORROSION	UNIFORM CORROSION	INTERNAL GEOMETRY	CRACK	INTERNAL/EXTERNAL CORROSION	MIN. BEND RADIUS (ft)	
BUCKLE DETECTOR	CONTRACTOR	N/A	N/A	GAUGING PLATE MECHANICAL SENSORS	WORLDWIDE	OPERATIONAL	EXTENSIVE	NO	NO	YES	NO	NO	SAGBEND	6.3-1
CAL-PIG	PIPTRONIX	≥ 6	N/A	MECHANICAL SENSORS	WORLDWIDE	OPERATIONAL	EXTENSIVE	NO	NO	YES	NO	NO	1.5 - 3	6.3-2
EGP	HROS	6 - 48	N/A	MECHANICAL SENSORS	WORLDWIDE	OPERATIONAL	LIMITED	NO	NO	YES	NO	NO	1.5 - 3	6.3-3
GAUGING PIG	TDW	2 - 36	N/A	GAUGING PLATE	WORLDWIDE	OPERATIONAL	EXTENSIVE	NO	NO	YES	YES	NO	1.5	6.3-4
GAUGING PIG	TDW	2 - 36	N/A	GAUGING PLATE	WORLDWIDE	OPERATIONAL	EXTENSIVE	NO	NO	YES	YES	NO	1.5 - 3	6.3-5
GAUGING PIG	INPIPE	1 - 48	N/A	MECHANICAL SENSORS	WORLDWIDE	OPERATIONAL	EXTENSIVE	NO	NO	YES	NO	NO	1.5 - 3	6.3-6
KALPER	TDW	8 - 60	N/A	ACUSTIC PINGER	WORLDWIDE	OPERATIONAL	EXTENSIVE	NO	NO	YES	NO	NO	-	6.3-7
PIG PINGER	HELLE	≥ 1	50,000 MAX.	ULTRASONICS	WORLDWIDE	OPERATIONAL	LIMITED	NO	NO	YES	NO	YES	1.5 - 6	6.3-8
FLAWSONIC	TDW	8 - 30	N/A	ULTRASONICS	NONE	UNKNOWN	NONE	YES	NO	YES	YES	YES	-	6.3-9
FLEXI-PIG 50000	RTD	-	N/A	ULTRASONICS	WORLDWIDE	OPERATIONAL	LIMITED	YES	NO	NO	YES	NO	1.5	6.3-10
MLD	MAHAK	8 - 40	N/A	ULTRASONICS	NONE	PROTOTYPE	LAB	YES	NO	YES	NO	YES	-	6.3-11
PIT 6000	RTD	≥ 16	-	ULTRASONICS	WORLDWIDE	OPERATIONAL	LIMITED	YES	YES	YES	NO	YES	1.5 - 3	6.3-12
ULTRASONIC TOOL	NKK	16 - 48	-	MAGNETS	WORLDWIDE	OPERATIONAL	EXTENSIVE	YES	NO	YES	NO	YES	1.5 - 5	6.3-13
CDP	HROS	6 - 48	N/A	MAGNETS	WORLDWIDE	OPERATIONAL	EXTENSIVE	YES	YES	NO	YES	YES	CASE BY CASE	6.3-14
LINALOG 360	TUBOSCOPE	4 - 48	N/A	MAGNETS	WORLDWIDE	OPERATIONAL	EXTENSIVE	YES	YES	YES	NO	YES	1.5	6.3-15
ON-LINE INSPECTION	BRITISH GAS	8 - 42	N/A	NEUTRON INTERROGATION	NONE	UNKNOWN	TEST	YES	YES	YES	NO	YES	-	6.3-16
BURIAL/COATING INSPECTION	BRITISH GAS	36	N/A	INTERROGATION	NONE	UNKNOWN	TEST	YES	YES	YES	NO	YES	-	6.3-16

ABBREVIATIONS:  
HROS - H. ROSEN ENGINEERING  
TDW - T.D. WILLIAMSON  
INPIPE - INTERNATIONAL PIPELINE PRODUCTS  
RTD - RONTGEN TECHNISCHE DIENST  
NKK - NIPPON KOKKAN K.K.

TABLE 6.2

# INTERNAL METHODS OF DAMAGE LOCATION AND ASSESSMENT

## **Chapter Seven**

### **MINOR INTERVENTION AND REPAIR**

## Chapter Seven

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## Chapter Seven

### MINOR INTERVENTION AND REPAIR

#### 7.1

#### INTRODUCTION

Minor intervention and repair is defined as procedures performed to correct deteriorations in the pipeline system. The work does not, in general, require any interruption or significant reduction of line production. In the context of the damage categorization scheme developed in Chapter Four, minor intervention and repair covers Damage Severity Levels 1 to 4.

Depending upon the type or degree of pipeline deterioration, minor intervention and repair operations may require prompt attention or may be deferred to a more convenient and economic time. It should be noted that minor pipewall damage (i.e. dent or gouge) is viewed to require repair initiation, not just intervention, and will therefore not be discussed in this Chapter. It should also be noted that although the terminology 'minor' is applied, it does not necessarily follow that the actual operation is minor in scope. For example, the correction of pipeline spans is a minor intervention since the operating status of the pipeline should not be affected; however, a correction procedure such as rock dumping can constitute a major offshore work effort.

Ancillary operations such as pipeline de-burial or weight coating removal, which may be required, are discussed in Chapter Eight.

It is assumed that before minor intervention operations commence, each area of pipeline damage detected is thoroughly investigated by visual inspection. Measurements of the extent of damage should also be made to enable a concise description of the damage to be prepared. On the basis of this description, the necessity, type and extent of any repair to be performed will be determined on an individual basis.

The procedures discussed in this chapter are summarized in data sheets at the end of this Chapter. The information is then compiled in matrix form in Table 7.1 for easy comparison of the individual repair techniques.

## **7.2 CORROSION AND WEIGHT COATINGS REPAIR**

### **7.2.1 Corrosion Coating**

Damage to the corrosion protection coating can occur due to external impact, age or the use of inappropriate coating materials and application practices.

It is difficult to achieve a good quality repair of damaged corrosion protection coating in a subsea environment. However, the manufacturers of certain types of two-pack epoxies claim that an effective coating can be achieved in the following process:

- 1) the damaged coating is removed from the area;
- 2) the exposed steel is cleaned by high pressure water jet or grit blasting;
- 3) the cleaned surface is inspected for possible defects; and
- 4) a suitable two-pack epoxy is mixed and spread over the exposed steel.

It should be noted that divers must take special precautions when using epoxy to avoid skin contact and inhalation of gases given off by the epoxy during curing if working in a saturation chamber. The need for diver assistance makes this kind of minor repair limited to operating diver depths.

Small areas of corrosion coating damage on the pipeline may be tolerated because the sacrificial anode system provides protection to areas of local damage. However, each area of damage detected should be considered individually and the necessity for eventual repair work determined.

### **7.2.2 Weight Coating**

Although the pipe steel wall thickness, in deep water will generally be great enough to provide a submerged weight sufficient for stability, in some cases, a weight coating may be necessary. Weight coating (i.e. concrete) damage may occur due to a number of causes but is typically caused by external impact or spalling of the concrete as a result of span vibration.

Small areas of damaged weight coating may not require repair unless pipeline stability is endangered. This can be established by a pipeline stability analysis which involves a knowledge of local soil and extreme environmental conditions.

A detailed assessment of the damaged area should be performed to ascertain whether additional damage has occurred to the pipeline, corrosion coating or anodes. If repair of a specific area of weight coating damage is required, it may be patched with a two-pack epoxy suitable for subsea application after cleaning the adjacent coating edges to provide a suitable key for the repair coating. For enhanced stabilization, the pipeline can be weighted by dumped stone, filled mattresses, or other post-pipeline stabilization techniques (see Sections 7.4 and 7.5).

Where freespanning has caused the original damage, span correction as set out in Section 7.4 will be required.

### 7.3

#### REPLACEMENT OF ANODES

Repair of the cathodic protection system may be required if anodes are lost through local impact, an area of excessive corrosion protection coating loss is detected or anodes are seen to be depleting faster than designed.

This repair could be achieved by fitting new, additional sacrificial anodes to the pipeline in the vicinity of the damaged or depleted pipeline anodes as outlined below:

- 1) the steel electrical bonding strap attaching the existing anode to the pipeline is cleaned to expose an area of bare steel (an area on the doubler ring around the pipe may alternatively be cleaned);
- 2) a new specially formed anode is clamped around the pipeline by bolting on the concrete coating adjacent to the existing anode;
- 3) a steel electrical bonding strap from the new anode core is either wet welded or cad welded to the cleaned area on the existing anode strap; and
- 4) an electrical resistance test of the electrical connection is performed to confirm continuity between anode and pipeline.

Other forms of retrofitted anodes are available, some of which are placed on a sled alongside the pipeline with an appropriate electrical connection.

## **7.4**

### **SPAN RECTIFICATION**

Pipeline spans can develop during pipelaying or be due to seafloor roughness or irregularities, scour below the pipe, bedform migration, and in some cases horizontal movement. Most spans are not a problem and the first step, once a span has been located, is to assess it with regards to induced stress levels and the potential for response to flow-induced vortex shedding. If a span is determined to be critical, then rectification is required but not necessarily on an emergency basis. The operator may justify a decision to leave a span until vessel availability improves or better weather conditions prevail, for example.

The criticality of a freespan is determined primarily by its length. The options available for reducing the length and height of a freespan include either supporting the span at discrete points or along the entire length, relaxing the stress levels by lowering seafloor high spots, or combinations of these two methods.

The feasibility of each option is dependent on the individual span characteristics, the nature and bearing capacity of the seafloor and the construction restraints imposed by the water depth.

In the case of spans formed after installation, rectification is generally limited to correction by stone dumping, grout bag placement or mattresses. Other techniques more applicable to scheduled interventions during construction are also briefly described.

It should be noted that damage to the weight coating may also occur as a result of induced vibration of a critical span, and therefore its repair should be undertaken concurrently with span rectification.

#### **7.4.1**

##### **Rock Dumping**

With this technique, the seafloor depression below a span is filled with dumped rock or gravel. The rock material and size used is a function of its stability against bottom currents and the loadings which will be encountered. The quantity of material required is dependent on the fill height, the number and length of spans and the accuracy of the dumping.

Quantities of the material may be reduced by limiting the extent of dumping to forming pillars as opposed to filling the complete span.

Normally the rock/gravel is quarried onshore (either custom made or existing quarries) and transported to an embarkation point for shipping.

Two systems are currently used for placing fill materials:

- 1) dumping through a fall pipe from a surface vessel, and
- 2) free dumping using side dump or split hopper vessels.

These methods are described on the data sheets at the end of this Chapter and may, with modifications, be applicable to deep water.

#### 7.4.2

##### **Grout Filled Bags**

Depending on the height of the spanning pipeline above the seafloor, and on the slope of the seafloor itself, correction can be undertaken utilizing various configurations and variations of grout filled bags. The bags are usually made of a woven fabric material. Individual cells are interconnected and grouted from inlets on various points on the bags. Grout bags have the advantage that they are easily handled and, when full, conform to the shape of the underside of the pipeline providing a stable support. Various configurations of grout bags are suggested for different span heights of up to 10 feet. With a combination of a telescopic cradle and a grouted base, span heights of up to 20 feet can be accommodated. On sloping bottoms, the grout bag tends to behave like a water filled balloon and roll down slope until the grout is set.

#### 7.4.3

##### **Other Techniques**

Span reduction can be achieved by means of pipeline trenching techniques where high spots are lowered to alleviate spanning. For spans occurring during construction this technique may be cost effective if a trenching spread is available. Post trenching an operating line is, however, potentially expensive and would only be employed where extensive spanning has developed.

Another alternative is mechanical towers such as those used for span correction on the Trans-Mediterranean pipelines. The device is lowered with ROV support from a dynamically positioned support vessel to the seafloor.

Once in place, the ROV actuates the hydraulically operated legs and raises and locks the pipeline support cradle. The operation is completely diverless; therefore the only depth restriction is that of the ROV. These devices are currently in place in water depths to 2000 feet.

## **7.5 PIPELINE STABILIZATION**

Portions of the pipeline may become unstable due to loss of weight coating or inadequate weight design. Stabilization may be provided by the following methods:

- 1) rock dumping;
- 2) overweighting using mattresses or concrete saddles;
- 3) anchoring using mechanical devices; and
- 4) trenching/burying the pipeline.

### **7.5.1 Rock Dumping**

Stabilization by rock dumping is accomplished using the same equipment/techniques described in Section 7.4.1.

### **7.5.2 Overweighting**

Overweighting can be conveniently carried out using bituminous rock filled mattresses. The mats, which can weigh up to 25 tons in air, are fabricated in a resilient woven fabric material filled with eight a Magnetite/Bitumen or Sand/Bitumen mix strengthened by a mesh reinforcement. They can be positioned directly onto the pipeline by surface vessels assisted by divers or remotely by utilizing a positioning frame.

Similar mattresses are now used extensively for a variety of applications including pipeline protection and pipeline crossings as well as footings for pipeline supports in areas of soft seafloor.

Concrete saddles work on the same principle any may be installed in the same manner. Care should be taken during their deployment, however, to prevent damage to the pipeline. Concrete saddles, being held in place by their own weight, need to be designed for their own stability under extreme loadings. Hence, they are often large, heavy and difficult to handle.

### **7.5.3 Anchoring**

Systems for mechanically anchoring pipelines are now commonly available and have been used extensively in shallow water, particularly in the Arabian Gulf. The usual system consists of an underwater crawler which is lowered onto the pipeline, tracking itself along by a system of guides. Twin drillheads enable two piles to be simultaneously bored into the seafloor on either side of the pipeline to then be secured in place by pumped grout. Divers or an ROV later bolt a saddle over the piles firmly anchoring the pipeline to the seafloor.

This type of system is suited to hard seafloors such as coral areas. Other forms of mechanical anchor devices use a screw system to drive helical anchors into the seafloor on either side of the pipe. This system also includes a saddle arrangement which sits over the pipe.

An important consideration with pipeline anchoring at discrete points (i.e. with saddles or mechanical anchors) is that the section of line between the anchors is effectively "unstable" and can move under the influence of extreme environmental conditions. The spacing between anchors should therefore be determined such that overstressing of the line will not occur.

### **7.5.4 Trenching/Burying**

Trenching/burying is appropriate for long sections of line which have become unstable or a lengthy section of line including multiple spans over an irregular bottom such as an area of migrating bedforms. Maintenance type trenching using conventional trenching techniques has been performed in both respects. The appropriate trenching techniques are those used for initial construction and include:

- high pressure jetting;
- low pressure jetting;
- mechanical trenching; and
- plowing.

In view of the mobilization costs of trenching and plowing spreads, it is unlikely that they would be used except in extreme cases where an extensive section of pipeline is affected. An example could be a deficiency in the original design or design data resulting in an installed line which is later found to be unstable.

Water jetting used to be limited to diver operation only; however, several of the ROV suppliers have developed their ROV designs to include powerful water jets. Plows are limited only by the pull force required to maneuver them and mechanical trenchers are limited only by their power cable requirements.

## **7.6**

### **SCOUR PREVENTION**

Where freespans are caused by scouring of the seafloor due to seafloor currents, further scour may be prevented by installation of anti-scour mats. Anti-scour mats act like seaweed to reduce the velocity of local seafloor currents causing sediment transport from the scoured area to be minimized. A localized area of scour may be infilled by dumped rock or gravel designed to be stable under local environmental conditions. It should be remembered that scour is not necessarily an adverse condition for a pipeline since it can promote self burial of the line in the long term and this aspect is the subject of recent studies and field testing and is considered an area worthy of further investigation. However, it should also be noted that the likelihood of scour in deepwater is very low.

## **7.7**

### **DATA SHEETS AND MATRIX**

This section contains data sheets which include pertinent information on the specific procedures for minor intervention. The data sheets follow the format and referencing system which is outlined in Chapter Three. The information found on each data sheet is then summarized and listed in Table 7.1 for ease of reference and comparison.

# DATA SHEET

**REFERENCE:** 7.2-1

**AREA:** Minor Intervention & Repair

**CATEGORY:** Coatings

**TECHNIQUE:** Corrosion and Weight Coating Repair

**DESCRIPTION:** Damaged area is cleaned, inspected and new material applied

## KEY PARAMETERS:

- **PIPE DIAMETER:** N/A
- **MAXIMUM WATER DEPTH:** Dependent on diver
- **MODE OF INTERVENTION:** Diver
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive

## ADDITIONAL INFORMATION:

- **Patch Material:** Two-pack epoxy
- **Required Equipment:** Pipe cleaning tools; epoxy application tools; support vessel; saturation spread
- **Alternate Weighting Techniques:** Stone dumping; grout bag or mattress placement

**REFERENCE:** Section 7.2

# DATA SHEET

**REFERENCE:** 7.3-1

**AREA:** Minor Intervention & Repair

**CATEGORY:** Anodes

**TECHNIQUE:** Anode Replacement

**DESCRIPTION:** New anode is clamped onto pipe adjacent to existing anode and connected by a steel electrical bonding strap

## KEY PARAMETERS:

- **PIPE DIAMETER:** N/A
- **MAXIMUM WATER DEPTH:** Dependent on Mode of Intervention
- **MODE OF INTERVENTION:** Diver/ROV
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive

## ADDITIONAL INFORMATION:

- **Required Equipment:** Replacement anode; clamp assembly; welding spread; pipe cleaning tools; torque wench; bolts and nuts; resistance testing equipment; support vessel; saturation spread

**REFERENCE:** Section 7.3

# DATA SHEET

REFERENCE: 7.4-1

AREA: Minor Intervention & Repair

CATEGORY: Span Rectification

SYSTEM: "SANDPIPER"

DESCRIPTION: Distributes stone/gravel through fall pipe

## KEY PARAMETERS:

- PIPE DIAMETER: N/A
- MAXIMUM WATER DEPTH: 2000 feet working
- MODE OF INTERVENTION: Vessel
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Extensive

## ADDITIONAL INFORMATION:

- Dimensions: 528 feet LOA, 32 feet draft
- Displacement: 29,321 tons
- Cargo Capacity: 20,393 tons
- Speed: 13.5 knots
- Other: Dynamic positioning; ROV; survey equipment
- Operator: Westheimer Offshore A/S

REFERENCE: Section 7.4.1

# DATA SHEET

**REFERENCE:** 7.4-2

**AREA:** Minor Intervention & Repair

**CATEGORY:** Span Rectification

**SYSTEM:** "TROLLNES"

**DESCRIPTION:** Distribute stone/gravel through fall pipe

## KEY PARAMETERS:

- **PIPE DIAMETER:** N/A
- **MAXIMUM WATER DEPTH:** 3280 feet
- **MODE OF INTERVENTION:** Vessel
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive

## ADDITIONAL INFORMATION:

- **Dimensions:** 367.5 feet LOA; 27 feet draft
- **Cargo Capacity:** 8818 tons
- **Speed:** 13 Knots
- **Other:** Dynamic positioning; ROV; survey equipment
- **Operator:** Van Oord ACZ

**REFERENCE:** Section 7.4.1

# DATA SHEET

**REFERENCE:** 7.4-3

**AREA:** Minor Intervention & Repair

**CATEGORY:** Span Rectification

**TECHNIQUE:** "JAN STEEN"

**DESCRIPTION:** Distributes stone/gravel/sand by side dump

## KEY PARAMETERS:

- **PIPE DIAMETER:** N/A
- **MAXIMUM WATER DEPTH:** 3280 Feet
- **MODE OF INTERVENTION:** Vessel
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive

## ADDITIONAL INFORMATION:

- **Dimensions:** 249 feet LOA; 12.8 feet draft
- **Cargo Capacity:** 2204 tons
- **Other:** Dynamic positioning or 4 point mooring system; 23.6 x 15.7 moonpool; optional Lucker 300T winch and/or Manitowoc 4600 S5 crane
- **Operator:** Van Oord ACZ

**REFERENCE:** Section 7.4.1

# DATA SHEET

**REFERENCE:** 7.4-4

**AREA:** Minor Intervention & Repair

**CATEGORY:** Span Rectification

**TECHNIQUE:** "ROCKY GIANT"

**DESCRIPTION:** Distribute stone/gravel/sand by side dump

## KEY PARAMETERS:

- **PIPE DIAMETER:** N/A
- **MAXIMUM WATER DEPTH:** 3280 feet
- **MODE OF INTERVENTION:** Vessel
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive

## ADDITIONAL INFORMATION:

- **Dimensions:** 325.9 feet LOA; 19.0 feet draft
- **Cargo Capacity:** 3748 tons
- **Other:** Dynamic positioning or 8 point mooring system; 16.4 x 23.0 feet moonpool
- **Operator:** Van Oord ACZ

**REFERENCE:** Section 7.4.1

# DATA SHEET

**REFERENCE:** 7.4-5

**AREA:** Minor Intervention & Repair

**CATEGORY:** Span Rectification

**TECHNIQUE:** Grout Filled Bags

**DESCRIPTION:** Bags placed under pipe and filled by diver or ROV

## KEY PARAMETERS:

- **PIPE DIAMETER:** N/A
- **MAXIMUM WATER DEPTH:** Dependent on Mode of Intervention
- **MODE OF INTERVENTION:** Diver/ROV
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive

## ADDITIONAL INFORMATION:

- **Required Equipment:** Support vessel with crane; inspection and work ROVs; grout mixer; saturation spread
- **Other:** Not suitable for sloping seafloor without special precautions to prevent slippage
- **Suppliers:** ADCO International

**REFERENCE:** Section 7.4.2

# DATA SHEET

**REFERENCE:** 7.5-1

**AREA:** Minor Intervention & Repair

**CATEGORY:** Pipe Stabilization

**TECHNIQUE:** Overweighting

**DESCRIPTION:** Bituminous mattresses or concrete saddles are placed over the pipeline by diver or remotely using a positioning frame

## KEY PARAMETERS:

- **PIPE DIAMETER:** N/A
- **MAXIMUM WATER DEPTH:** Limited by Mode of Intervention
- **MODE OF INTERVENTION:** Diver/ROV
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive

## ADDITIONAL INFORMATION:

- **Required Equipment:** Support vessel with crane; saturation spread
- **Suppliers:** ADCO International - grout mattresses  
SeaMark System - "FLEXIWEIGHT", "FLEXIWEIGHT MASSIV MESH", "SEAMAT", "STARMAT"

**REFERENCE:** Section 7.5.2

# DATA SHEET

**REFERENCE:** 7.5-2

**AREA:** Minor Intervention & Repair

**CATEGORY:** Pipe Stabilization

**TECHNIQUE:** Anchors

**DESCRIPTION:** Pipeline is secured to seafloor by piles or screws installed by diver or ROV

## KEY PARAMETERS:

- **PIPE DIAMETER:** N/A
- **MAXIMUM WATER DEPTH:** Dependent on Mode of Intervention
- **MODE OF INTERVENTION:** Diver/ROV
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive

## ADDITIONAL INFORMATION:

- **Required Equipment:** Support vessel with crane; saturation spread; installation crawler/machine and spread
- **Other:** More suited for hard seafloor materials such as dense sand or coral; section of pipe between anchors may become overstressed due to movement

**REFERENCE:** Section 7.5.3

# DATA SHEET

**REFERENCE:** 7.5-3

**AREA:** Minor Intervention & Repair

**CATEGORY:** Pipe Stabilization

**TECHNIQUE:** Trenching/Burying

**DESCRIPTION:** Pipe is covered with overburden by diver or ROV using jets, trenching machine or plows

## KEY PARAMETERS:

- **PIPE DIAMETER:** Dependent on Mode of Intervention
- **MAXIMUM WATER DEPTH:** Dependent on Mode of Intervention
- **MODE OF INTERVENTION:** Diver/ROV/Trencher/Plow
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive

## ADDITIONAL INFORMATION:

- **Required Equipment:** Support vessel or barge with crane; saturation spread; jetting tools; trenching machine and spread; plow and survey vessel
- **Other:** Plows are usually custom designed for use during installation; powered units such as jetting machines and mechanical trenchers may become inefficient and difficult to handle due to power requirements and cable/umbilical lengths

**REFERENCE:** Section 7.5.4

# DATA SHEET

**REFERENCE:** 7.6-1

**AREA:** Minor Intervention & Repair

**CATEGORY:** Scour Prevention

**TECHNIQUE:** Anti-Scour Mats

**DESCRIPTION:** Mats placed around pipeline to prevent movement of sediment out of the area

## KEY PARAMETERS:

- **PIPE DIAMETER:** N/A
- **MAXIMUM WATER DEPTH:** Dependent on Mode of Intervention
- **MODE OF INTERVENTION:** Diver/ROV
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive

## ADDITIONAL INFORMATION:

- **Required Equipment:** Support vessel with crane; saturation spread; handling frames
- **Other:** Scour may promote self burial in the long term; scour unlikely in deepwater
- **Suppliers:** ADCO International - "CEGRASS"  
SeaMark Systems - "FLEXIFROND"

**REFERENCE:** Section 7.6

METHOD	KEY COMPARISON PARAMETERS					REQUIRED EQUIPMENT	ADDITIONAL INFORMATION AND COMMENTS	DATA SHEET REF.	
	WATER DEPTH (FEET)	MODE OF INTERVENTION	AVAILABILITY	DEVELOPMENT STATUS	EXPERIENCE				
CORROSION AND WEIGHT COATING REPAIR	DEPENDENT ON MODE	DIVER	WORLDWIDE	OPERATIONAL	EXTENSIVE	<ul style="list-style-type: none"><li>• TWO-PACK EPOXY</li><li>• PIPE CLEANING, APPLICATION TOOLS</li><li>• SUPPORT VESSEL W/ DIVING SPREAD</li></ul>	<ul style="list-style-type: none"><li>• ALTERNATIVES INCLUDE ROCK DUMPING AND GROUT BAG/MATTRESS PLACEMENT</li><li>• DIVER SHOULD AVOID SKIN CONTACT W/ EPOXY AND INHALATION OF EPOXY FUMES</li></ul>	7-2-1	
ANODE REPLACEMENT	DEPENDENT ON MODE	DIVER/ROV	WORLDWIDE	OPERATIONAL	EXTENSIVE	<ul style="list-style-type: none"><li>• REPLACEMENT ANODE AND CLAMP ASSEMBLY</li><li>• PIPE CLEANING, APPLICATION TOOLS</li><li>• RESISTANCE TESTING EQUIPMENT</li><li>• SUPPORT VESSEL W/ DIVING SPREAD</li></ul>		7-3-1	
SPAN RECTIFICATION	FALL PIPE	3280	VESSEL	WORLDWIDE	OPERATIONAL	EXTENSIVE	<ul style="list-style-type: none"><li>• VESSEL WITH VERTICAL PIPE FOR DUMPING SUCH AS "SANDPIPER" OR "TROLLNES"</li></ul>	<ul style="list-style-type: none"><li>• VESSELS EQUIPPED W/ DP, ROV AND SURVEY EQUIPMENT</li><li>• CARGO CAPACITY FROM 8000 TO 30,000 TONS</li><li>• MOST ACCURATE METHOD OF ROCK PLACEMENT</li></ul>	7-4-1 AND 7-4-2
	SIDE DUMP	3280	VESSEL	WORLDWIDE	OPERATIONAL	EXTENSIVE	<ul style="list-style-type: none"><li>• VESSEL SUCH AS "JAN STEEN" OR "ROCKY GIANT"</li></ul>	<ul style="list-style-type: none"><li>• VESSELS EQUIPPED W/ DP OR MOORING SYSTEM AND MOONPOOL</li><li>• CARGO CAPACITY FROM 2000 TO 4000 TONS</li></ul>	7-4-3 AND 7-4-4
	GROUT BAGS	DEPENDENT ON MODE	DIVER/ROV	WORLDWIDE	OPERATIONAL	EXTENSIVE	<ul style="list-style-type: none"><li>• GROUT MIXER</li><li>• SUPPORT VESSEL W/ CRANE AND DIVING SPREAD</li></ul>	<ul style="list-style-type: none"><li>• EACH BAGS HAS 1 OR 2 FILLING ACCESSSES</li><li>• CAN FILL SPAN COMPLETELY OR BE PLACED AT INTERVALS</li><li>• NOT SUITABLE FOR SLOPING SEAFLOOR</li></ul>	7-4-5
	OVERWEIGHTING	DEPENDENT ON MODE	DIVER/ROV	WORLDWIDE	OPERATIONAL	EXTENSIVE	<ul style="list-style-type: none"><li>• SUPPORT VESSEL W/ CRANE AND DIVING SPREAD</li></ul>	<ul style="list-style-type: none"><li>• MAY BE MATS OR LOOSE, DUMPED ROCK</li><li>• ALSO USED FOR CROSSINGS</li></ul>	7-5-1
PIPE STABILIZATION	ANCHORS	DEPENDENT ON MODE	DIVER/ROV	WORLDWIDE	OPERATIONAL	EXTENSIVE	<ul style="list-style-type: none"><li>• INSTALLATION MACHINE AND SPREAD</li><li>• SUPPORT VESSEL W/ CRANE AND DIVING SPREAD</li></ul>	<ul style="list-style-type: none"><li>• BETTER SUITED FOR HARD SEAFLOOR</li><li>• PIPE BETWEEN ANCHORS MAY BECOME OVERSTRESSED DUE TO MOVEMENT</li></ul>	7-5-2
	TRENCHING/ BURYING	DEPENDENT ON MODE	DIVER/ROV/ TRENCHER/ PLOW	WORLDWIDE	OPERATIONAL	EXTENSIVE	<ul style="list-style-type: none"><li>• SUPPORT VESSEL W/ CRANE, DIVING SPREAD, AND JETTING TOOLS</li><li>• TRENCHING MACHINE AND SPREAD OR PLOW AND SURVEY VESSEL</li></ul>	<ul style="list-style-type: none"><li>• JETS ARE ADAPTED OR SPECIFICALLY DESIGNED FOR ROV USAGE</li><li>• TRENCHERS LIMITED BY POWER REQUIREMENTS</li><li>• PLOWS USUALLY CUSTOM DESIGNED AND LIMITED BY PULL FORCE REQUIREMENT</li></ul>	7-5-3
	SCOUR PREVENTION	DEPENDENT ON MODE	DIVER/ROV	WORLDWIDE	OPERATIONAL	EXTENSIVE	<ul style="list-style-type: none"><li>• HANDLING FRAMES</li><li>• SUPPORT VESSEL W/ CRANE AND DIVING SPREAD</li></ul>	<ul style="list-style-type: none"><li>• SCOUR MAY PROMOTE PIPE SELF BURIAL IN THE LONG RUN</li><li>• SCOUR UNLIKELY IN DEEPWATER</li></ul>	7-6-1

TABLE 7.1

MINOR INTERVENTION AND REPAIR

## **Chapter Eight**

### **INTERMEDIATE AND MAJOR REPAIR**

## Chapter Eight

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## Chapter Eight

### INTERMEDIATE AND MAJOR REPAIR

#### 8.1 INTRODUCTION

This Chapter of the manual concentrates on repair techniques for pipeline systems suited to the intermediate or major level of damage as defined in Chapter Four. The key difference between intermediate and major damage is that the major damage defines a situation where the pipeline system must be taken out of commission. The consequences of the shutdown in terms of restart or recommissioning requirements depends largely on the specific details of the pipeline system and the repair undertaken.

It should be noted that the actual repair technique for intermediate or major damage can be the same. Therefore, the repair techniques are not grouped in terms of intermediate or major repair situations but in broad terms which define the technique or equipment used to make the repair:

- 1) established construction techniques and equipment;
- 2) proprietary hardware;
- 3) integrated repair systems; and
- 4) alternative subsea welding techniques.

Within each group both established techniques and developmental procedures are presented.

In some cases, there is an interdependence between techniques. For example, the use of certain mechanical connectors (proprietary hardware) could involve the application of hyperbaric welding (established construction technique).

In addition to the four primary groupings of repair techniques, ancillary operations which precede or follow a repair operation are presented. These include operations such as pipe deburial, pipe end preparation, etc.

## 8.2 ESTABLISHED CONSTRUCTION TECHNIQUES

This section discusses the established construction techniques for repair and replacement of a damaged pipeline. The techniques include:

- 1) hyperbaric welding;
- 2) repair during pipelay;
- 3) surface lift;
- 4) flanged spoolpiece connection; and
- 5) hot tap and bypass.

### 8.2.1 Hyperbaric Welding

#### 8.2.1.1 General Description

Hyperbaric welding is a thoroughly developed method of marine pipeline connection and is widely used as a repair method by operators worldwide.

This method of welding is performed by diver/welders in saturation who are sent down to a habitat. The habitat is at the same pressure as the surrounding seawater and contains the types of tools for welding which are found in a typical fabrication shop. The present practice is to make the initial weld pass (root bead) using the Tungsten Inert Gas (TIG) process. This process can be slow and tedious for the diver/welders due to the pipe end alignment and high weld quality control requirements. The remainder of the welding is completed using manual metal arc welding. This may require several weld passes depending on the pipe diameter and wall thickness.

#### 8.2.1.2 Repair Procedure

Before mobilizing to the offshore location, the hyperbaric weld procedure and diver/welders are qualified under simulated offshore hyperbaric conditions.

The first stage of the actual repair operation consists of flooding the pipeline (if not already flooded) so that the interior and ambient pressure along the pipeline are equal. Divers or ROVs are sent down to survey the damage and jet away overburden which might hamper the lifting of the pipe ends during the repair. This task is followed by cutting and removal of the damaged section. The next stage is to install inflatable plugs in the open ends of the severed line. These plugs are not required to withstand high pressure differentials but are merely intended to prevent any later drawing of water into the habitat from the flooded pipes. Guidelines are then

attached to the pipe by the divers or ROVs in order to assist in the positioning of the alignment frame which is lowered from the repair vessel to the pipeline on the seabed. This frame may or may not include the welding habitat (varies between contractors).

Movable clamps on the alignment frame are fastened on each pipe end. The clamps are moved and closed hydraulically by the diver or ROV. After closing the clamps on the pipe ends to firmly hold the pipeline, the ends are raised to clear them of the seabed and moved until the pipe ends are accurately aligned.

Some larger, heavier pipelines, however require additional support and alignment beyond that of a simple alignment frame. In this case, H-frames can be used to provide the extra lift capacity. Prior to installation, the H-frame positions are surveyed for stability. Once approved, the support vessel crane lifts and lowers the first H-frame into position on one side of the actual repair location. The H-frame is then hydraulically clamped to the pipe end and the clamps are raised to lift the pipe above the seabed. The pipe can then be moved until it is back in line and can be handled by the alignment frame. The procedure is then repeated for the adjacent pipe section. The H-frames will continue to support the weight of the pipe during the repair while the alignment frame provides final alignment for the welding procedure. Once the pipe ends are aligned, the habitat, if not already positioned, is lowered from the support vessel into the alignment frame. An umbilical links the habitat with the support vessel. The welding habitat consists essentially of a relatively light rectangular steel box, open at the bottom with a short slot at each end to accommodate the pipe.

When lowered over the pipe and secured in position, shims and neoprene seals are fitted between the end slots of the habitat and the pipe before the water is displaced from inside the habitat by an oxygen-helium mixture supplied through the umbilical. The pressure inside the habitat is maintained at the surrounding water pressure to prevent inward leakage of water; consequently, the habitat-to-pipe seals are only required to withstand a very small pressure differential. At this stage, the interior water level at this stage lies just above the bottom of the habitat.

Then the diver/welders under saturation can be transferred 'dry' from the surface to the habitat via a diver lock-out submersible or a specialized transfer module. A carbon dioxide scrubber, dehumidifier and reheater control the atmosphere within the habitat and habitat conditions are monitored by an electronic analyzer which transmits relevant data to the

surface. The monitoring equipment and other life support equipment are contained in a support unit on the support vessel (refer to Section 5.2.2 for full details on saturation diving).

The rough cut pipe ends are accurately cut and bevelled to match a spoolpiece contained within the habitat. The spoolpiece is lowered between the pipe ends, and all weld surfaces are cleaned. Spacers are inserted to ensure correct clearances, and an external alignment clamp is installed. Weld preheating is carried out, if required, and the first of the two welds is made. The weld is examined by X-ray or gamma radiography. The films are brought to the surface, processed and examined by inspectors. A similar procedure is undertaken for the second weld.

When both welds are accepted, the joint area is wrapped with a cold applied tape or shrink sleeve to provide corrosion protection. After the welding/inspection/ wrapping operations are complete, the diver/welders are transferred back to the surface. The habitat is then flooded and raised to the surface and the alignment frame clamps (or H-Frames) lower the pipe back to the seafloor and release it. The welding operation is complete when the alignment frame (and H-frames) are raised to the surface. If the length of repair required is long, a large spoolpiece will be required. Each end will be welded into the pipeline using the above procedure and the complete repair operation will, therefore, require two successive hyperbaric welding operations on the seafloor.

#### 8.2.1.3

##### Suppliers/Vendors

Several companies offer hyperbaric welding services and have extensive experience worldwide. They include:

- Comex Services;
- Global Divers;
- Rockwater; and
- SubSea International.

Descriptions of each company's technique and equipment are given in the data sheets at the end of this Chapter.

#### 8.2.1.4 Additional Methods

In addition to replacement of sections of pipe by welding, a number of other weld repair methods are being used in the industry. Each of these methods tends to be suitable to a specific type of damage which does not require replacement of the pipe. These methods, which also involve the use of a hyperbaric habitat, are as follows:

- Weld Reinforcement is used for sections of a pipeline which have local reductions in the wall thickness such that the resultant hoop stress is increased but no leakage has occurred. The weak areas are reinforced by infilling with weld metal. The damaged area of pipe is ground back, weld metal is added raising the area above that of the surrounding pipe wall, and then the weld metal is ground level.

This effectively leaves a common wall thickness with a uniform hoop stress. The resulting wall thickness shall be greater than the nominal wall thickness.

This method's main advantages are that pipeline operation can be maintained while the reinforcement is completed and, for small repair areas, the actual work content is the least of all repair methods. The method is suited to local corrosion (pitting corrosion), grooves, gouges and/or notches without cracks. This method can be applied to either an operating or flooded pipeline.

- Half-Soling can be applied to either leaking or non-leaking defects. The defect (corrosion groove, gouge, notch, or dent) is covered by a curved section of plate, one-half the circumference of the pipe.

Extensive tests have been carried out to determine the effectiveness of the half-sole method. Results indicate that while their effectiveness can be assured, it is dependent on an accurately controlled fit between the pipeline and the half-sole. Control of fit becomes more difficult with the increase of the thickness of the plate.

- Non-Pressure Encirclement Sleeve repair is carried out by the encapsulation of a section of the pipeline by two semi-circular sleeves. The sleeves are normally only weld connected along the longitudinal seams; however, they can be seal-welded to the pipeline by girth welds.

Non-pressure sleeves are designed to support the non-leaking, damaged section of pipe by transference of hoop stresses to the sleeves and prevention of flexure or bulging at the point of damage. Similar problems as in the half-sole method of fitting the plate properly to the pipe exist. This method is directly comparable to a split bolted sleeve, which carries out the same function.

- Full-Pressure Encirclement Sleeve repair is similar to the non-pressure sleeve described above, except that it is designed to accept full pipeline operating pressure and is suitable for leaking and non-leaking damage. Construction normally requires butt welds which are backed longitudinally with steel plate and fillet girth welds. Since the repair accepts full pressure, only the ends need to be welded on the seafloor; therefore the entire assembly should be fitted within one dry habitat to be cost effective. This fact limits the maximum suitable length of the sleeve to 6-10 feet. As there is invariably more weld metal in a full pressure sleeve than in a similar pipeline replacement section, any damage which requires flooding of the pipeline is best repaired by section replacement.

This method is suited to all forms of pipeline damage, except sharp defects which could lead to cracking or that have cracks themselves, defects which prevent suitable pipeline operation because of internal restriction or out-of-roundness, or defects which have caused a change in direction of the pipeline.

## 8.2.2 Repair During Pipelay

Generally, a pipeline is most susceptible to damage during construction when the pipeline may either buckle over the suspended section and during hydrotesting when small scale damage or welding defects may develop leaks or fractures under the test pressure.

Failure of pipeline systems in service is a rare occurrence and is generally attributed to impact from construction vessel anchors, fallen objects, mud slides or corrosion.

Pipeline buckles during the construction phase must be treated differently depending on the type:

- Dry Buckle where the pipeline has deformed sufficiently to be outside specification tolerances or to prevent the passage of pigs (i.e. the line has not ruptured and is still fully water tight) or
- Wet Buckle where a full or partial rupture occurs and the pipeline fills with seawater.

#### 8.2.2.1 Dry Buckle Repair

Dry buckles can occur in the pipeline suspended sagbend length due to adverse weather conditions, faulty tensioning equipment or poor lay vessel operation, possibly in combination with external pressure effects.

A buckle detector in the form of a gauging plate may be deployed in the pipeline near the foot of the sagbend. The detector is towed by a cable connected to a tension gauge. As the lay vessel moves forward after the welding of each pipe joint, the tension gauge is monitored and any abnormal increase in tension is noted.

When abnormal tension is noted, it is possible that the detector has hung up on an ovality or dent. By relating the known length of cable to the high tension reading, the suspect sections of pipeline can be located and divers/submersible dispatched to investigate.

If a dry buckle is confirmed, it is normal practice for the lay vessel to "reverse lay" back to the damaged section. As each pipe joint passes through the last tensioner, the pipe is cut and a joint is removed. During this time, tension is maintained in the pipe span to prevent the buckle from worsening. The procedure continues until the buckle is brought past the last tensioner. The buckled section is then removed. The pipe end is cut and beveled and normal pipelay operations resume. The pipe joints which were removed are inspected and may be reused if possible.

#### 8.2.2.2 Wet Buckle Repair

Wet buckles occur when the pipeline ruptures either completely or partially and becomes filled with seawater.

Pipelines may be equipped with buckle detectors which are capable of activating seals when a large pressure differential occurs, thus limiting the flooding to a reasonably short distance. Otherwise, the line floods until internal pressure is equalized by the remaining compressed air. If the pipeline does not fracture and is lost, the lay vessel may still have to abandon the pipeline due to the increased submerged weight.

Once a wet buckle is suspected, the lay operation is halted and tension is increased on the pipeline. A laydown head is then welded onto the pipe end and attached to a abandonment and recovery (A & R) winch cable. The tension in the A & R winch cable is increased while simultaneously the tension provided by the tensioners is reduced to zero. The pipe tensioners are then released and hold back is maintained by the A & R cable alone. The lay vessel then moves forward until the laydown head reaches the seafloor.

Depending on the water depth, a diver or ROV is sent down to locate and determine the extent of the wet buckle. Once the damage is assessed, the lay vessel is positioned over the damage and divers or ROVs cut the pipe to remove the damage. Depending on the water depth and submerged weight of pipe, the line may have to be dewatered at this time so the lay vessel can retrieve it to the surface. If so, the divers or ROVs will install a perforated dewatering pig trap on the pipe end. The pig trap will double as the recovery head once dewatering is complete. The pipeline is dewatered from the opposite end and the A & R winch cable is attached to the pull head.

The lay vessel is then repositioned and the pipeline is recovered to the surface using the A & R winch. The cable is reeled in while the lay vessel moves backwards until the pull head passes through the tensioners. Tension is transferred back to the pipe tensioners and the A & R winch cable is removed. The pull head is removed and the pipe end is cut and beveled. Normal lay operations are then resumed.

It is not always necessary to complete the lengthy task of dewatering the pipeline before the repair can begin. In some cases the A & R winch is capable of handling the increased pipe weight. Another way of decreasing the pipe load is to attach buoys along the line. A recent development allows recovery of wet buckled pipelines from any water depth by pulling the pipeline directly on the stinger and tensioners. This patented procedure is offered by Diverless Systems. Where applicable, any of these methods are quicker and more cost effective than dewatering a long line.

### **8.2.3 Surface Lift**

#### **8.2.3.1 General Description**

One procedure which is widely used throughout the industry is known as the surface lift. By using several davit lines attached along the pipeline the pipe end can be raised above the surface. This allows the welding

procedure to be completed above water. The surface lift includes several variations of repairs. The first is the surface weld repair, which is often performed in shallow water where it is an effective technique and offers significant advantages in terms of schedule and cost compared to other techniques. Surface weld repairs in waters deeper than 200 feet require a larger construction vessel or two lift vessels to support the pipe ends simultaneously. Furthermore a higher risk exists of causing further damage to the pipeline during the repair operation due to the S-curve configuration which is required. These considerations tend to negate the advantages of the technique over the other lift techniques in deepwater.

In deepwater the surface lift can be used to attach a swivel, flange or connector to the pipe end. Since the actual connection is flexible or subsequently made subsea, the pipe end is not required to be horizontal at the surface and, in turn, the pipe is less likely to overstress. Depending on vessel/davit capabilities and the availability of suitable lengths of pipeline for lifting in catenary to the surface, any repair where the pipe is cut and has free ends can be done by this method. Its major advantage is that no specialized diver/welding or habitat equipment is required. Diving/ROV capability will be required, however, for initial attachment and removal of lift cables.

#### 8.2.3.2

##### Surface Weld Repair

This repair operation begins by cutting free the damaged pipeline section and lifting it clear. Mechanically connected end caps containing valves are then bolted on to the free pipe ends by divers/ROVs. The valves allow water flow through the pipe end and the end cap acts as a pig trap during dewatering operations. The support vessel is aligned along the axis of the pipeline at a predetermined distance from one pipe end. Davit lines are then used to haul in the pipeline until it reaches the surface where it is clamped into an alignment frame supported by the vessel. The end cap is removed, the pipe end bevelled, and a prepared spoolpiece is welded to the section. This additional length of pipe replaces the damaged pipe section and allows for an overlap in the pipe ends which is necessary during tie-in.

The free end of the spoolpiece is capped and davit lines are attached and tensioned before the alignment frame is released. The pipeline is lowered to the bottom and support vessels are repositioned for lifting of both pipe ends simultaneously. Both sections are then lifted to the surface by davits.

After the spoolpiece has been connected and the welds approved, the pipeline is lowered to the bottom. The lowering is accomplished by a

combination of vessel sideways movement and payout of the davit cables according to a predetermined schedule.

#### 8.2.3.3 Surface Swivel Repair

The surface lift/surface swivel repair method is a variation of the surface weld repair. All procedures are carried out in the same manner, except that a swivel or flexible pipe section is welded to each pipe end to make the connection rather than the pipe ends being welded together. This eliminates the need for exact alignment of the pipe ends for welding.

#### 8.2.3.4 Bottom Connect Repair

The surface lift for this repair scenario follows the same steps for lifting the pipeline to the surface as in the surface weld repair except that one pipe end is picked up at a time. The damaged pipe section is removed and mechanically connected end caps containing valves are attached to the pipe ends. The lines are dewatered (if necessary) and the barge moves to set up along the first pipe end. The pipe end is then picked up using davits which have been attached at predetermined spaces along the pipe. The pipe is brought to the surface alongside the barge and a scaffolding is built to support the welding crew. The pipe end is cleaned, cut and beveled and a flange is welded on. The weld is X-rayed, approved and coated and the pipeline is lowered to the bottom. Divers/ROVs are sent down to take a measurement between the flange and opposite pipe end. The davit lines are unhooked and the barge moves over the opposite pipe end. The pipe end is picked up to the surface, and as before, the proper spool length and flange are welded to the pipe end.

Once the spool to pipe end weld is completed and approved, the pipeline is lowered to the seafloor opposite the other pipe and flange. The davit lines are used to manipulate the flange into position. Once in position, the flanges are made up by using a hydraulic tensioning tool operated by the diver/ROV. The metal to metal seal is pressure tested and all equipment is brought to the surface. The bottom connect repair is complete.

#### 8.2.4 Flanged Spoolpiece Connection

There are cases where damage may occur within flanged sections of a pipeline. This includes tap valves, mid-line tie-ins, offsets near a platform, expansion loops, etc. If the damage is extensive and must be removed, flanged spoolpiece connections can be made to repair the pipeline.

In this method of repair the damaged section of pipe is removed by divers/ROVs using hydraulic wrenches to unbolt the flanges at each end. The damaged section is then brought to the surface. Divers/ROVs will inspect the flanges which are left at each end of the pipeline for any damage. If they are damaged and must be replaced, the previously described flange repair procedure can be used. Assuming the flanges are not damaged, divers/ROVs are sent down to assist in the alignment of the two pipe ends. Where excessive misalignment between the two flanges is evident they must be aligned by sidewalking the pipes using davit lines. Alternatively bends can be incorporated in the design of the spoolpiece.

Once the flanges are in their final position, the distance, angular misalignment and offset between them are measured using a template spoolpiece. This is brought back to the surface and the spoolpiece is fabricated in accordance with the template measurements, tested and then lowered into position.

Modifications to the spoolpiece may be required before a satisfactory fit between the flanges is attained. These modifications are performed on the surface so this operation can be time consuming.

When a satisfactory spoolpiece fit is obtained, the flange connections are made up by rotating the swivel rings on the spoolpiece flanges until the bolt holes align with those on the pipeline end flanges. This allows the stud bolts to be inserted and then tensioned to the required value using hydraulic tensioning equipment. The stud tensioning equipment is removed on completion of flange make-up and the flange joints are leak tested by pressure testing the pipeline.

## **8.2.5 Hot Tap And Bypass**

### **8.2.5.1 General Description**

A hot tap is a means of cutting a hole into a pipeline which is in service and under pressure without allowing the contents to escape. The procedure requires a fitting, a valve, a tapping machine and a pressure holding device. Without shutting down the pipeline, a fitting is connected to the pipe (by welding or mechanical means) and a valve is installed on the fitting. The tapping machine is then engaged and makes the tap into the pipeline through the valve. The valve is closed and the tapping machine is removed.

The branch connection is now ready to receive a tie-in piece, an infield line, a bypass, etc. This procedure is widely used offshore in a maintenance capacity because it requires no shutdowns and minimal ancillary equipment and the cost is relatively low.

#### 8.2.5.2

##### Repair Procedure

A fitting is installed on either side of the damaged section. The fittings accommodate the plugging valves and are used to connect the bypass line to the pipeline. The fittings encircle the pipeline and can be welded or mechanically secured to the line. Each fitting is equipped with a flange to mate with the tapping machine. Once these fittings are in place, a sandwich tapping valve and the tapping machine are lowered to the repair site. The sandwich valve is used to shut off the flow through the fitting once the tap has been made. This is essential since during the repair several pieces of equipment will be installed and removed. The system is attached to one of the fittings and a tap is made. The coupon (section of pipe which is removed from the line being tapped) is cut away and backed out using the tapping machine. The sandwich valve is then closed either manually by turning a handle or hydraulically by using a hydraulic ram. The tapping machine is now removed with the coupon and the procedure is repeated at the other fitting. A bypass line is then lowered to the fittings and flanged to the sandwich valves. The sandwich valves are opened and the product is free to flow through the flowline.

Plugging machines are installed atop the two fittings and plugging heads are hydraulically lowered into the original line between the bypass line and the damaged section. The damage section can now be removed and replaced using whatever spoolpiece replacement technique is most readily available or cost effective. Once the new section is in place the bypass line and plugging tools are replaced with flange plugs installed with a tapping machine. After this operation has been completed at each fitting, the tools and sandwich valves are removed and recovered to the surface. Blind flanges are then installed to replace the valves.

#### 8.2.5.3

##### Suppliers/Contractors

Several companies offer hot tapping services and have extensive experience worldwide. They include:

- HydroTech System;
- Plidco International; and
- T.D. Williamson.

A description of T.D. Williamson's technique and equipment is given in the data sheets at the end of this Chapter.

## **8.2.6 Limitations and Applicability**

### **8.2.6.1 Hyperbaric Welding**

Over the years hyperbaric welding in an enclosed habitat has been the most reliable method with the widest experience for joining two pipe ends together in a subsea environment. As a pipeline repair tool, the system is capable of supporting pipe wall reinforcement, pipe wall replacement (by welding circular sleeves about the pipe), pup piece repair and spoolpiece repair (replacement of entire sections of pipe). Damage to the pipe can range from minor damage due to corrosion or major damage caused by dropped objects or anchor impact, for example. Therefore, hyperbaric welding handles a wide range of repair situations and is applicable to virtually all types of damage. The technique does, however, have certain limitations.

Firstly, hyperbaric welding is a water depth sensitive procedure. Beyond practical maximum diving depths for subsea work (currently up to approximately 1000 feet) the welding procedure becomes prohibitive. The safety and quality workmanship of the diver/welders actually becomes suspect closer to 600-700 feet below the water surface. Secondly, the H-frames, alignment frames and welding habitats all require a fairly level and stable seafloor. This can be remedied by the use of hydraulic legs with incorporated mud mats, or by a diver/ROV equipped with a hand jet to level out the repair area. However, this is not always feasible and sometimes the terrain is at such a slope that installing the equipment is impractical. A third limitation is the economics of the operation. Since at deeper waters (i.e. over 700 feet) the safe and efficient working time of the divers diminishes, a fixed amount of work can only be accomplished by increasing the number of working divers and, hence, the cost. Depth therefore places a physical limit on diver working time and economic penalty on performing work at greater depths. Other limitations pertain to precise pipe and alignment and minimum out-of-round pipe tolerance.

Future efforts are being aimed towards increasing the divers work depth limit by altering the existing breathing gases that are now being used. Testing work is aimed at extending work capability to 1500 feet. Beyond this, automatic welding systems have been developed which do not require diver control in the habitat. The systems still need diver/ROV assistance, though, to prepare and align the pipe ends. One study is currently

underway in the United Kingdom to extend hyperbaric welding to 3000 ft with modifications to the welding habitat.

#### 8.2.6.2 Repair During Pipelay

This method of repair applies to any damage that may occur during the pipelay procedure. If the pipeline is dry damaged, the vessel must back up under the line while cutting out pipe sections until the damaged section is onboard. This technique requires very minor subsea intervention and is not limited by water depth except depth limitations of the pipelay operation itself.

To date, pipe has been laid in waters exceeding 2000 feet. Inspection of the damage severity can be performed by ROV as well as a diver. The repair is made up onboard after which time pipelay may be resumed.

Wet damage which occurs during pipelay requires that the pipeline be transferred from the tensioners to an A&R winch cable and subsequently laid down on the seafloor. Pigging is then required to purge the line of water and reduce its submerged weight for recovery. This requires that the damaged section to be cut out and the A&R winch line reattached to the new pipe end. ROV's can perform the diver tasks for this procedure. If ROV intervention is not achieved, repair of this type is limited to approximately 1000 feet (practical diver working depth limits). Once the line is purged and the A&R winch cable is reconnected there are no limits of water depth as long as the A&R winch is capable of handling the load required to get the pipe end back to the surface. The repair is made onboard and pipelay can be resumed.

#### 8.2.6.3 Surface Lift

There are several types of surface lift methods which are used in a repair capacity by contractors worldwide. For example, variations of the surface lift method are widely used as a repair tool in the Gulf of Mexico quite frequently. However, all surface lift techniques are subject to the condition that the pipeline can be lifted freely and safely from the seafloor to the water's surface. Consequently, the deeper the water, the heavier the load and more comprising the pipe configuration. The methods of repair that involve lifting the pipe ends to the water's surface are discussed below.

This repair method is a variation of the surface lift/surface weld method in that the connection is made on the surface. A short piece of flexible pipe or swivels are flanged or welded to each pipe end. For this operation the pipe ends need not be horizontal alongside the support vessel since the swivels or flexible pipe allow for the misalignment between the pipe ends.

Once the connection is made, the vessel will move laterally as it lowers the repaired pipe to the seafloor. This maneuver allows for any slack in the line. The method has not been widely used to date, due to the other options available to the client which repair the pipeline without modifying the bottom pipeline configuration. However, this method may be a viable alternative in deepwater where diving operations could be prohibitive as well as expensive.

Another type of surface lift repair incorporates flanges which can be welded to each pipe end separately above water allowing a subsequent installation subsea. This eliminates the need for the pipe to be horizontal at the surface which results in less stress along the pipe. The procedure is primarily limited by the davit lifting capacity of the vessel and the subsea portion of the repair. To date, this procedure has been limited to less than 500 feet; however, with the attachment of buoys to the pipe to lighten the load (for heavy lines) and the increased ability of ROVs to perform diver tasks (i.e. completing a flange for a connection) this procedure is now a valid alternative in deepwater in excess of 1500 feet.

Surface lift repairs are applicable to any substantial damage wet or dry that requires the replacement of a pipe section. The method would not be cost effective for small superficial damage where day rates synonymous with davit carrying vessel are prohibitive.

#### 8.2.6.4

##### Flange Spoolpiece Connection

The subsea flanged spoolpiece repair is depth limited only by the ability of an ROV to perform the diver tasks required to complete the connection. These tasks are required to complete the connection. These tasks include jetting out and clearing the repair area of any debris, removing studs and bolts from each flange so the damage can be removed, assisting in the guidance of the new spoolpiece into position and the completion and testing of both flanges. According to ROV manufacturers, this is within the capabilities of existing work ROVs. Several completely diverless repair systems are currently under development and should be available within the next two years.

This type of repair is applicable to any of the categories of damage as described in Chapter Four that occur within a flanged section of pipe. If the section is fairly short, say less than 40 feet, it will be replaced rather than patched even if patching is all that the damage requires. For a longer damaged section, the use of a split-sleeve clamp for minor repair may be more cost effective than replacing the damaged section. Where the

damage is severe enough to require a replacement section regardless of the length, the flanged repair will always be performed.

This repair method is usually found to be effective near platforms where flanged sections of pipe are the most abundant (i.e. riser connections, tie-ins, component systems, etc.).

#### 8.2.6.5

##### Hot Tap & Bypass

The hot tapping of one pipeline for the purposes of connecting another smaller pipeline has been performed successfully offshore for many years. The advantage of this method is that it does not require shutdown of a working line. This can be very cost effective, especially for long lines, where purging and recommissioning of the line can take weeks. However, the incorporation of a bypass with a pair of taps into the same line as a repair procedure, although successful onshore, has several limitations offshore.

First, the equipment which is available to perform this type of repair (subsea) is only operable to approximately 550 feet. Other repair methods in this range are more prevalent and in some cases less expensive. Secondly, purging and recommissioning the pipeline will be required for wet damage no matter what repair method is used. This negates one of the major advantages of the hot tapping sequence. The hot tapping and bypass sequence is only a temporary repair. Therefore, this repair method is only applicable to dry damage where purging and recommissioning of the pipeline is considerably more expensive.

#### 8.2.7

##### **Data Sheets and Matrix**

This section contains data sheets which include pertinent information on the established construction techniques. The data sheets follow the format and referencing system which is outlined in Chapter Three. The information found on each data sheet is then summarized and listed in Table 8.1 for ease of reference and comparison.

## **8.3 PROPRIETARY HARDWARE**

### **8.3.1 Introduction**

Proprietary hardware repair systems can be grouped into the following categories:

- 1) mechanical connectors;
- 2) mechanical connectors requiring welding;
- 3) cold-forged connectors;
- 4) split-sleeve clamps; and
- 5) valve components.

Mechanical connectors incorporate bolts and studs to initiate a metal-to-metal and/or elastomer seal about the pipe end. Cold-forged connectors fit their inside diameter to the pipe end outside diameter using a hydraulically powered tool or pressure to make the metal-to-metal seal. Both of these systems can incorporate slip joints, ball flanges and rotating flanges to ease installation and allow for misalignment. Both systems are also common for spoolpiece repair where a section of pipe has been damaged.

Split-sleeve clamps are used to repair small, localized pinholes, dents or gouges by bolting or hydraulically actuating the clamp around the damage to produce the metal-to-metal and/or elastomer seal.

### **8.3.2 Suppliers/Vendors**

Proprietary hardware is provided by several companies. Although each company's tools and equipment are similar, the design and installation procedures are different. Each of the following suppliers/vendors are discussed:

- Big Inch Marine Systems
- British Gas/Elf Aquitaine
- Cameron Iron Works
- Gripper
- HydroTech Systems
- Oceaneering International
- Plidco International
- Stress Engineering
- Vetco Gray

In addition to the proprietary hardware, different valve types and valves component maintenance and repair are discussed.

### 8.3.2.1

#### Big Inch Marine Systems (BIMS)

BIMS uses the "Flexiforge™ System" which is based on their patented cold forging process. This method avoids the need for both pipe end retrieval and welding. The connection process is as follows:

- 1) After pipe ends have been cleaned, squared off, and inspected, the Flexiforge Forging Tool Assembly is stabbed into the pipe end. The Flexiforge End Connector and Counter-Torque Grip will align and fit over the outside of the pipe simultaneously.
- 2) The forging tool is activated to rotate rollers inside the pipe. As the rollers rotate, they expand inside the pipe forcing the pipe to yield circumferentially until the external surface of the pipe is forced into complete contact with the grooves on the internal surface of the Flexiforge End Connector.
- 3) The connection is ultrasonically inspected throughout the entire forging process to ensure a complete 360° metal-to-metal seal is achieved.
- 4) After completion of the forging process, the Counter-Torque Grip is released and the bolts securing the Forging Tool to the End Connector are removed.
- 5) Steps 1 through 4 are repeated for the other pipe end.
- 6) A spoolpiece is fitted between the standard flanges at the pipe ends.

BIMS produces misalignment ball joints and ball flange connectors (also available reversible and boltless) which can accommodate axial and angular misalignment of the pipe ends. Both of these devices employ metal-to-metal seals and allow  $\pm 12.5^\circ$  misalignment. The ball joints are designed for use with the Flexiforge End Connector and the ball flanges connect directly to a standard RTJ flange.

### 8.3.2.2

#### British Gas/Elf Aquitaine

In 1989, British Gas and Elf Aquitaine began testing of their prototype diverless pipeline repair system, Titus (tie-in tools for underwater systems) on a 20 inch pipe. The repair is a metal-to-metal seal between the pipe end

which is cold forged into a flare and a cone inserted into the pipe end. The cone is part of the hydraulically actuated connector.

The complete system consists of master flanges (which fit around the pipe end), the connectors, and a spoolpiece. The spoolpiece is made of steel bends welded into an S-shaped loop and the connectors are welded to each end of the loop.

The repair process is two-fold. First, the pipe end is flared, then the actual connection is made. The pipe end flaring process, shown in Figure 8.1a, is as follows:

- 1) The pipe end is square cut in preparation for the repair, but it is not necessary to remove the corrosion coating or dress the longitudinal welds. This work is accomplished by tools on the base frame which secures and supports the pipe ends.
- 2) The hydraulically activated forming tool is positioned at the pipe end and automatically fits the master flange and external anchoring device over the outside of the pipe and inserts an internal anchoring device into the pipe. An ultrasonic head on the anchoring devices assures proper alignment.
- 3) With the master flange in place, the anchoring devices are activated to secure the flange and pipe and the forming tool is advanced into the pipe. As the forming tool moves forward, it flares the pipe end against the master flange.
- 4) Once the flaring procedure is complete, the internal anchoring device is released and removed along with the forming tool. The external anchoring device remains with the master flange on the pipe end.
- 5) Steps 1 through 4 are repeated for the other pipe end.

The actual connection process, as shown in Figure 8.1b, is executed as follows:

- 1) The special-made spoolpiece is retracted, lowered into position onto the base frame, and released so that the connectors at each begin to engage the master flanges. Hydraulic pressurization of the connector moves the connector teeth completely through the flange teeth.

- 2) Hydraulic motors rotate the outer casing of the connector to interlock the connector and flange teeth.
- 3) Continuing hydraulic pressure compresses and yields a metal ring attached to the face of the connector to produce the metal-to-metal seal.
- 4) The hydraulic motors secure a locknut on the connector to maintain the pressure at the connector/flange interface. This allows disengagement of the hydraulic pressure.
- 5) Steps 1 through 4 are repeated for the other end of the spoolpiece.

The connector behaves like a ball-joint for misalignments of  $\pm 3^\circ$  and has been internally pressure tested to 12,900 psi for two hours with no detected leaks.

#### 8.3.2.3

##### Cameron Iron Works, Inc.

Cameron uses their cold forging Camforge™ Repair System in conjunction with various components to make a pipeline repair. All components have metal-to-metal seals. The connection process is as follows:

- 1) The damaged section is removed and the pipe ends cleaned and squared off. It is not necessary to remove the epoxy coatings or the weld seams.
- 2) The sleeve, forging element, retrievable connector, and the tie-in base are lowered in one step to the seafloor.
- 3) The swing clamps are closed onto the pipe end and the packer is hydraulically stroked, stabbing the forging element into the pipe and the sleeve over the pipe.
- 4) Once the forging element and the sleeve are in position, hydraulic pressure is applied through the forging port expanding the forging element against the bore of the pipe. Pressure is increased causing the pipe to radially expand and locally deform against the bore of the sleeve. The sleeve is elastically expanded to near its yield point. Then, the forging pressure is released leaving the pipe forged to the sleeve. The volume compensating rings absorb any water trapped between the seal shoulders during the forging process.

- 5) After the forging is complete, the seal integrity is tested at the pipeline pressure.
- 6) The retrievable connector is unlocked, the packer is hydraulically stroked to pull the forging element out of the pipe, and the swing clamps are opened. Then the running tool is recovered leaving the sleeve and the tie-in base on the pipeline ready for the spoolpiece connection.
- 7) Steps 2 through 6 are repeated for the other pipe end.
- 8) A spoolpiece is installed completing the repair.

The sleeves on the pipe ends act as receivers for the spoolpiece. The spoolpiece typically includes standard Cameron collet connectors and a swivel assembly with two mid-point swivels.

The collet connectors may be any of the following types: non-integrated, integrated, structural, self-aligning or multi-bore. The swivel assembly may be a combination of single, double or remotely locking swivels. All swivels allow for  $\pm 10^\circ$  misalignment. A length compensating joint with either metal-to-metal or elastomer seals may also be included in the swivel assembly.

#### 8.3.2.4

##### Gripper, Inc.

The Gripper Pipeline Repair System consists of a number of components which are used in various combinations to make a pipeline repair. The actual connection is made by the Gripper Ball Connector-Flange Lok (GBCFL) which makes a permanent metal-to-metal seal and allows a flange misalignment of  $\pm 10^\circ$ . The GBCFL can mate with the Grip and Seal Mechanical Coupling (GSMC), Gripper Metal Seated Coupling (MSC) and Grip and Seal Hydraulic Coupling (GSHC).

The connection process is as follows:

- 1) After the pipe ends have been cleaned and squared off, a GBCFL is installed on each pipe end with the ball element inboard.
- 2) The spoolpiece length is measured and made-up with ends consisting of a GSMC, MSC or GSHC.

- 3) The GBCFL automatically grips the pipe end and as the nuts are tightened, the metal nose of the ball imbeds itself into the metal cup.
- 4) The seals are externally pressure tested to demonstrate their integrity. If the test indicates a defective seal, the components can be disassembled, cleaned, and reassembled until an acceptable test is completed.

Gripper now also offers a hydraulic ball connector to substitute for the GBCFL. The hydraulic connector automatically centers the pipe for maximum seal effectiveness and allows for thermal expansion of the pipe. As with GBCFL, the hydraulic connector allows  $\pm 10^\circ$  misalignment and may be tested after installation.

For additional axial adjustments, the spoolpiece may be fitted with a Gripper Pipe Length Compensator (GPLC). The GPLC utilizes a metal-to-metal seal which may be tested. The system may also allow for angular compensation if used in conjunction with the GBCFL.

All of the above referenced components are shown in Figure 8.2.

#### 8.3.2.5

##### HydroTech Systems, Inc.

HydroTech Systems offers two pipeline repair systems: 1) Spool Piece Repair Set (SPRS) for damaged areas equal in length to two pipe diameters and greater and 2) Pipeline Repair Unit (PRU) for damaged areas less than two pipe diameters in length. The SPRS is comprised of two Spool Piece Repair Units and a spoolpiece. Each repair unit consists of a Mark V HydroCouple with an extension nipple and a Misalignment Flange (MAF). The PRU consists of only two Mark V HydroCouples and one MAF. Neither repair system requires the use of a heavy construction barge since the pipe need not be lifted to the surface nor is hyperbaric welding required as all welding may be performed on the support vessel. The connection process for the SPRS is as follows:

- 1) After cutting away the damaged section, the pipe ends are squared off, weight and mastic coatings removed and the weld bead crown of the longitudinal weld seam is flattened.
- 2) The Mark V HydroCouple of each Spool Piece Repair Unit is stabbed on the pipe ends. It is structurally connected to the pipe by the self-locking segments which wedge between the pipe outside diameter and an outer wedged-shaped "bowl" on the HydroCouple.

- 3) A spoolpiece with a MAF housing welded to each end is lowered between the Spool Piece Repair Units and moved to achieve centerline intersection.
- 4) The Spool Piece Repair Unit is moved forward and stabled over the ball on the MAF housing. The seals and slips are set simultaneously by tightening the packing flange on the HydroCouple. When axially compressed, the elastomeric seals flow radially inward against the pipe and outward against the HydroCouple.
- 5) The diver tests the seals by pressuring the annulus between them with a hydraulic hose.

The PRU is installed similarly. The HydroCouple on one end has the ball of the MAF and the other has the MAF socket. These two pieces are stabbed together to make the connection.

Before it is locked, the HydroCouple may be adjusted axially by one pipe diameter or 12 inches, whichever is greater. This feature combined with the  $\pm 10^\circ$  misalignment of the MAF gives the SPRU several degrees of misalignment capabilities.

#### 8.3.2.6

##### Oceaneering International

Oceaneering's Smart Flange Plus is a sparkless alternative to spoolpiece repairs which eliminates the need for pipe end retrieval and subsea welding. All operations can be performed by a WASP or ROV. The connection process is as follows:

- 1) Spoolpiece section is measured and fabricated.
- 2) After the damaged pipeline section is isolated, a cold-cut is made at pre-determined locations to accommodate the spoolpiece length plus 1.5 inches. The extra length allows for the Smart Flange Plus piston lip.
- 3) A Smart Flange Plus mechanical connector with ring-type gaskets is placed on each of the cleaned and prepared pipe ends.

- 4) The prefabricated spoolpiece is inserted and one set of mating flange nuts are set and torqued.
- 5) Second end of spoolpiece is set and connected with the Smart Flange Plus compensating for the needed extra length.

Torque on the upper nuts automatically sets the Smart Flange Plus and load is transferred to the flanges to protect the elastomeric seal; therefore over-torquing will not damage the Smart Flange Plus or the pipeline. For misalignment, the flange may be swiveled during installation. Every Smart Flange Plus manufactured is connected to a blind flange and fully tested before delivery.

A Smart Flange Plus currently holds the record for the world's deepest mechanical connector installation at 1430 feet water depth in the Gulf of Mexico by ROV. For ROV installation of a Smart Flange Plus, the ROV is equipped with a work skid, docking tool and hydraulic hot stab.

#### 8.3.2.8

##### Plidco International

Plidco manufactures the Split + Sleeve and the Weld + Ends Coupling which can be used to repair small scale damage such as dents, gouges and pinhole leaks where replacement of the damaged section is not necessary.

The Split + Sleeve is a welded, permanent clamp which can be installed while the pipeline remains online. It has patented GirderRings which hold the factory-installed elastomer packings in place to prevent their displacement by leaking fluids during installation. This clamp can achieve high pressure seals over pitted pipe, surface irregularities and small dimensional discrepancies. The installation process is as follows:

- 1) All coatings, rust and scale are removed from the pipe surface where the Split + Sleeve is to be assembled.
- 2) A lubricant compatible with the seal and product is used to coat all exposed surfaces of the gasketing and the nuts and bolts.
- 3) The sleeve is assembled loosely to one side of the leak, then slide over the leak, centered as much as possible and the nuts and bolts hand tightened. The bolt holes automatically line up.

- 4) To complete the assembly, all the nuts and bolts are uniformly torqued as recommended while maintaining an equal gap all around between the side bars. All bolts should be rechecked and a slight gap should exist between the side bars.
- 5) If welding is specified, the pipeline should be first in full operation. The following welding sequence should be used: a) fillet weld ends; b) seal weld sides; c) seal weld bottom of nuts; and d) burn off bolt ends flush to nuts and seal weld.

Plidco also offers the R + C Installer which automatically positions and hydraulically closes the Split + Sleeves by remote control to increase personnel safety.

The Weld + Ends is a coupling which incorporates clamp and thrust screws to join two pipe ends and produce a metal-to-metal seal. No special preparation of the pipe ends is required. The installation process is as follows:

- 1) The coupling is slipped completely over one pipe end. A wide gap should be left between the pipe ends to eliminate alignment. One half of the coupling length is marked off from the gap to center the coupling over the joint.
- 2) After the coupling is positioned over the gap, the clamp and thrust screws are torqued tight. The thrust screws compress the packing ring causing the packing to flow out between the coupling and pipeline.
- 3) If welding is specified, the pipeline should be first in full operation. The following welding sequence should be used: a) burn or cut off thrust screws flush; b) fillet weld ends; c) seal weld thrust screws; and d) burn or cut off clamp screws flush and seal weld.

#### 8.3.2.8

##### Stress Engineering

Stress Engineering is currently developing the preliminary design for a diverless clamp installation tool which works with a pipeline repair clamp and ROV for a completely diverless repair of a subsea pipeline.

The installation tool is based on existing repair clamp technology but alternative fastener designs to the current standard bolt will be explored before the final design.

Only basic ROV capabilities will be needed by the clamp installation tool. The ROV will deliver the clamp to the repair site, provide hydraulic power to the tool and provide additional sensory equipment as necessary. All other necessary installation equipment will be onboard the tool and the repair clamp will have a minimum of expendable equipment.

#### 8.3.2.9

##### Vetco Gray

The Vetco Gray Grayloc® connector is an alternative to the standard flange connection. It has a simple, efficient sealing design where the internal pressure of the pipe actually increases the sealing pressure. Reusable, metal sealing rings lend to the efficiency of the connector.

A Grayloc connector consists of the seal ring, hubs and a clamp assembly. the seal ring has a "T" cross-section where the base of the "T" is a rib clamped between the hub faces and the top forms lips which deflect against the inner surface of the hubs of form the seal.

To assemble, the clamp fits over the two hubs. As the hubs are drawn together by the clamp, the seal ring rib ensures alignment and the lips deflect elastically against the inner surface of the hubs forming a self-energizing seal.

In operating conditions, the internal pressure of the pipe reinforces the seal. Once the connection is complete, the Grayloc connector is comparable to a welded joint in sealing integrity.

The Grayloc connector can be either diver assisted with four bolts or remote with three trunnion and screw mechanisms. Remotely, the clamp is activated by applying torque to either hexagonal head of each drive screw. Reverse torque releases the clamp. Both types of connectors are reusable without refurbishment and may be affixed at any orientation to allow easier access to the bolts or screw mechanisms.

#### 8.3.3

##### **Valve Repair**

Valve repair operations consist of tasks of varying degrees of complexity depending upon the valve design. Three of these valve designs are:

- conventional valves which are integral with the pipeline and are replaced by removal of a complete pipe spool;
- modular valves which allow removal and replacement of the valve internals from the valve body as a complete unit; and
- in-situ repairable valves which require maintenance of all replaceable components.

Ball-types only are assessed for the for the conventional and modular valves, while both ball and gate types are assessed for the in-situ repairable types.

#### 8.3.3.1

##### Conventional Valve

The principal feature of the conventional ball valve is that the body has no bolted bonnet or body joints and is therefore "sealed-for-life". Ports are provided in the valve body to allow the injection of sealant to the ball and stem seals in the event of leakage. Valve operation is by a removable double-barrelled hydraulic actuator.

Since internal parts such as the ball, seats, seals and bearings cannot be accessed, repair is accomplished by replacement of the entire valve. No subsea actuator maintenance other than complete removal and replacement is required. This is the most common procedure used for the repair of subsea valves.

#### 8.3.3.2

##### Modular Valve

The modular valve is designed such that all maintainable components are housed in a replaceable core unit within the valve body. Access to the core is top entry for ease of removal and the bore of the body is tapered to reduce the possibility of jamming. The valve core, top entry bonnet and actuator can be removed from the body as one unit by opening a split-manacle clamp which holds the bonnet to the valve body.

Semi-plastic sealant compounds can be injected into the valve seats and stem seals through ports in the valve body to provide emergency secondary sealing if required. This valve uses the same type of double-barrelled hydraulic actuator as the conventional valve.

Subsea work on the actuator is confined to removal and replacement operations.

valve types are capable of sustaining several types of external and internal damage. External causes may include dropped objects, construction operations, etc. Internal damages may range from corrosion and seal deterioration (due to the pipeline contents) to pigs becoming stuck, equipment failures, pressure increases, etc. The applicability of the repair of these valves depends on the type of valve, the water depth in which it is located and the types of repair or replacement operations that are capable of bringing the valve back on line. The water depth limitations at this time is governed by diver depth limits. However, the modular valve designs which incorporate retrievable component units may be ROV friendly. If so, the water depth limit for valve repair would increase dramatically.

### **8.3.5 Data Sheet and Matrices**

This section contains data sheets which include pertinent information on the five categories of proprietary hardware and on specific pieces of equipment and its supplier. The data sheets follow the format and referencing system which is outlined in Chapter Three. The information on each data sheet is also included in Tables 8.2 and 8.3 for ease of reference.

## **8.4 INTEGRATED REPAIR SYSTEMS**

### **8.4.1 Introduction**

The increasing trend towards deepwater pipeline installation has resulted in the study and development of several integrated pipeline repair systems. The current trend in these pipeline repair options is towards modular systems capable of being deployed by available dynamic positioning (DP) support vessels.

Such systems are designed to operate in a diverless mode and consequently may prove cost effective for permanent standby pipeline repair contingency programs.

Several studies and development programs have been conducted in recent years and the systems developed or proposed by the following organizations are described in the subsequent sections:

- Ferrostaal AG
- International Submarine Engineering
- Saipem spa
- Snamprogetti spa
- SonSub Services

#### 8.4.2 Ferrostaal AG

The submarine pipeline repair system, Submersible Underwater work and Pipeline Repair Apparatus (SUPRA), was developed as a joint venture between several German companies headed by Ferrostaal. SUPRA was designed not to be a ROV or submersible but a large, powerful subsea intervention machine which is surface towed by a diving support vessel thereby eliminating the need for a major surface support vessel such as a crane barge equipped with heavy handling gear.

The SUPRA vessel consists of two each longitudinal floats and girders. These are connected by vertical supports and athwartships girders. This catamaran type steel structure consists of pressure hull and pressure equalized sections. All systems required to operate the vessel are contained in the atmospheric compartments and are accessible when SUPRA is submerged because the vessel can support two divers for operations if necessary.

The vessel is approximately 121 feet in length with a 40 feet breadth; is self-propelled by 10 thrusters to achieve a maximum forward speed of 2.5 knots; has a 44 ton payload capacity; and is rated to 1380 feet water depth.

Standard equipment includes:

- four hydraulic levelling supports;
- one or two 22 ton gantry cranes hydraulically positioned on rails which run the entire length of the vessel;
- pipe alignment system consisting of four hydraulically operated alignment frames with pipeline clamps;
- hyperbaric welding system with dry or wet transfer of divers;
- one-atmospheric diving bell;

- range of hydraulic plugs for hand held and remote tools;
- up to eleven external cameras with viewing from two monitors;
- obstacle avoidance sonar; and
- surface compactors, vibratory pile drivers, core drilling unit, dredging equipment, and two diesel generators.

Optional equipment consists of:

- transfer platform which replaces welding habitat to transfer heavy equipment from surface to seafloor;
- 3.8 ton capacity telescopic swivel crane with manipulators;
- personnel transfer system;
- saturation diver compartment and transfer system; and
- manual and automatic welding systems.

The SUPRA is designed to transport these heavy work units to the seafloor and deploy them for inspection, testing, and repair procedures.

#### **8.4.3 International Submarine Engineering (ISE)**

ISE developed their Tethered Remote Automated Pipeline Repairer (TRAPR) to be a large, tethered workhorse capable of performing submarine tasks, such as pipe deburial, cutting and end preparation, plug installation and hardware actualization, with a large variety of tools and tool packages.

The TRAPR is 16.2 x 7.7 x 10.3 feet; weighs 24,000 lbs; has 4000 lbs forward thrust and 6000 lbs of controlled lift; and is rated to 3280 feet water depth.

Standard equipment includes;

- two each, 1500 lbs lift capacity, 7 function manipulators;
- assistance vehicle with tether management system on 150 feet working radius and 1 x 4 function manipulator for light work tasks;

- Pipe Preparation Module with a water jet and milling head to remove the concrete and cut the pipe;
- Multi Service Clamp for guide line installation and pipe handling and lifting;
- Plug Installation Module which cleans the pipe and installs and inflates both plugs; and
- 5 cameras with single or dual 500 W lights per camera, telemetry, gyro, altimeter and sonar.

The TRAPR works in conjunction with the Module for Assisting Robotic Systems (MARS) to perform automated welded tie-ins. The MARS is equipped with Comex's latest automated hyperbaric welding spread. The TRAPR assists in positioning the pipe lifting frames, Comex's Seahorse alignment frame and the welding habitat on the seafloor. Then the MARS is docked on the habitat to dewater it and fill it with argon.

The ancillary and welding equipment on the MARS includes:

- Pipe Machining Tools to cut, bevel and bore the pipe ends;
- Pipe Alignment Controller which performs accurate metrology of the pipe end positions;
- Loading Arm Robot (LAR), an 8-axis, heavy duty arm robot, which installs and actuates all the work modules in the interactive or program control modes and performs any unplanned tasks in the manual control mode;
- Comex's Tig Hyperbaric Orbital Robot (THOR) to perform the welding;
- Tool Orbital lamp to correct out-of-roundness and support the other tools; and
- Piece Clamp which positions the pup piece and holds the preheating pads.

The TRAPR and MARS are shown in Figure 8.3. For complete details on Comex's THOR welding system refer to Section 8.5.

#### **8.4.4 Saipem Spa**

Saipem is currently involved in the development and trials of a diverless deepwater pipeline repair system. However, information on this system is strictly confidential, but will be available in the Fall of 1992.

#### **8.4.5 Snamprogetti spa**

Snamprogetti, together with Perry Technologies, has developed a deepwater pipeline repair system which consists of two separate components:

- 1) a large, remotely operated thruster module ROV to provide deployment assistance, positioning, power, controls and observation and
- 2) a series of six underwater work system service modules designed to perform specific tasks associated with the pipeline repair.

The 3000 feet rated thruster module ROV consists of 8 x 10 x 14 vehicle with 200 hp, wet mateable hydraulic and electric connections, and two RECON IV work ROVs to remotely monitor the work site activities.

The series of service modules consist of the following:

- 1) dredge module for pipe deburial and site preparation;
- 2) two "H" frames to lift and support the damaged section;
- 3) preparation module to remove the concrete and protective coatings, cut the pipe and prepare the pipe ends;
- 4) module to recover the cut-away damaged section;
- 5) connector and spoolpiece module made-up of the following subsystems:
  - base frame with measuring device to determine length of spoolpiece
  - alignment frame to position pipe ends
  - end connector and spool installation trolley
  - hydraulic cold forging device to install end connectors; and

6) spoolpiece repair joint comprising:

- two ball end connectors
- telescopic slip joint
- two socket end connectors with spring fingers
- intermediate distance pieces.

The entire repair process is monitored and assisted by the two RECON IV vehicles which are connected to a computer on the support vessel with touch screen software control windows.

The spoolpiece repair joint is designed to replace up to a 40 feet section of pipe, allow  $\pm 10^\circ$  misalignment, correct axial measurement errors up to one pipe diameter, verify seal integrity after connection and permit passage of intelligent pigs.

#### 8.4.6

#### **SonSub Services/Cameron Iron Works**

SonSub Services has developed a pipeline intervention support package designed around proven ROV technology and interface hardware systems. The diverless intervention system targets hazardous and remote, deepwater environments. The hub of the package is the Challenger advanced remotely operated vehicle system (AROWS) which is a powerful and versatile system rated to 3280 feet and able to support six, key hardware subsystems utilized for remedial work, repair, mid-point tie-ins and recovery during pipelay.

The interface hardware subsystems include:

- 1) ROV powered and operated dredge system;
- 2) heavy duty expandable packers filled by a positive-displacement pump on the ROV which elevate the pipeline off the seafloor;
- 3) reciprocating guillotine saw or grit-entrained saw with ROV supplied power and controls to cut-out the damaged section of pipe;
- 4) high pressure water blaster deployed by an ROV manipulator mounted nozzle or dedicated jig or ROV deployed rotary saw and jig to split and remove the concrete weight coating;

- 5) Cameron Iron Works' Camforge™ cold forging repair system; and
- 6) spoolpiece to replace damaged section with a Cameron collet connector at each end.

For complete details on Cameron Iron Works' Camforge™ system and their other hardware, refer to Section 8.3.

#### **8.4.7 Data Sheets and Matrix**

This section contains data sheets which include pertinent information on integrated repair systems. The data sheets follow the format and referencing system which is outlined in Chapter Three. The information found on each data sheet is then summarized and listed in Table 8.4 for ease of reference and comparison.

### **8.5 ALTERNATIVE WELDING TECHNIQUES**

This section discusses welding techniques which may be substituted for hyperbaric and includes the following systems:

- Comex's "THOR";
- SubSea International's "OTTO"; and
- Wet welding.

Several other welding techniques, which employ a welding method other than the tungsten inert gas (TIG) process, are also discussed.

#### **8.5.1 Comex's THOR**

Comex Services has developed their Tig Hyperbaric Orbital Robot (THOR) with preprogrammed welding procedures so that it may be completely diverless (ROV controlled) or need only limited diver intervention. THOR is currently used by the International Submarine Engineering remote systems TRAPR and MARS (refer to Section 8.4.2 for details).

THOR consists of the following components:

- support and alignment tracks installed around the pup piece;
- welding head containing the carriage, oscillator, torch and umbilical; and
- weld pool observation system which allows surface operator close-up views of both sides of the weld.

The welding head includes a series a carriages, each with its own guidance system, to carry the wire reels and feeders. Two wire feeder assemblies and reels allows welding in both directions.

The torch position relative to the weld centerline can be pre-programmed or set by the surface operator. This adjustability allows for irregularities and misalignment in joint preparation.

The weld pool observation system includes two video cameras for viewing and inspection, a microphone to record "arc sound", and arc light "eliminator" units to enhance viewing.

### **8.5.2 SubSea International's OTTO**

SubSea developed the first automatic orbital welding system (OTTO) for use below 1000 feet. In procedure mode, OTTO allows storage of procedures for multiple welding tasks simultaneously. Once in production mode, the operator may vary some of the welding controls to ensure conformance. A fiber optic viewing system allows immediate inspection of the weld as it is made. The OTTO system is completely remote once set up either by diver or ROV.

### **8.5.3 Wet Welding**

Wet welding utilizes the electric arc method with the stick electrode completely submerged in water. Its major drawback is the porosity in the weld caused by gas bubbles. Bubbles are attributed to the welding rod design.

The major advantage of wet welding is economies; it does not require a dry habitat. However, it is not preferable to hyperbaric welding in situations where the welds are subjected to high fatigue and stress levels.

## 8.5.4 Additional Welding Techniques

Some of the following welding techniques discussed are not available for offshore use; however they are included because they have potential and add information and completeness.

### 8.5.4.1 Explosive Welding

Concern for the repair of deepwater pipelines has led Oil & Gas Project Consultants of Holland to investigate a repair system the utilizes explosive welding. Explosive welding for metal lining/cladding is already established for shop applications, but its exact potential in offshore/wet locations is not yet determined. It offers the following advantages:

- metal welding/fusion without conventional equipment;
- internal/external welding without human intervention;
- available knowledge about using explosives as applied to cladding/linings, plugging of nozzles, tubes, etc.;
- remote operation to position/locate repair tool; and
- remote triggering of the explosive device as already established in the nuclear industry.

Current intelligent pig technology will be incorporated into the development of the system to ensure pigs safe, unobstructed passage.

The system is expected to complete full-scale trials in Spring 1993.

### 8.5.4.2 Electron Beam Welding

Electron beam welding uses the finely focused beam of electrons produced by an electron gun to form a narrow, deep weld. To produce the weld, the pipe ends need only be square cut and free from contamination and minor misalignment of the pipe ends will not effect the weld quality.

The welding chamber and gun chamber must be in a vacuum during the welding process. This is achieved by inflation of two annular seals around the outer surface of the pipe ends and by the setting of two internal seals.

#### 8.5.4.3

##### Flash Butt Welding

In flash butt welding, a large current is passed between two pipe joints where local melting takes place because of the produced heat. The pipe ends are then forced together to make the weld. Pipe preparation requires only a square cut with no bevel. The two sections of the pipeline are clamped and electrical contact shoes are fitted to both sections. An alternating, low voltage, high current source is then connected to the pipes and they are moved slowly together. When electrical contact occurs at surface irregularities, resistance heating and high local current densities cause electrical arcing at points of contact. After a predetermined time, the pipe ends are moved together more rapidly causing the welding current and flashing to increase.

Finally, a large axial force is applied to force the pipe ends together. This expels molten metal and undesirable oxides and forges the parts together. After welding, an internal flash remover shears debris from the pipe interior while an orbiting milling machine tools the outer surface. Finally, the weld is normalized by inductively heating the joint then cooling it.

#### 8.5.5

##### **Limitations and Applicability**

Many of the welding techniques described in this section are alternatives or refinements to hyperbaric welding for the purpose of offshore pipeline repair. These techniques are applicable to damage which requires the replacement of a pipe section in water depths beyond hyperbaric welding limits. One-atmosphere welding has been developed to increase a divers normal depth limit and allow pipeline repair welding in water depths beyond 1000 feet. Automated welding is designed to remove the human element from hyperbaric welding and increase the technique's depth limit as well as its quality by reducing the risk of defects. Some automated welding systems, however, still require pipe end and equipment preparation by a diver before the system can be operated. Wet welding and the additional welding techniques discussed in this section do not all apply to offshore pipeline repair at this time, although research and development is ongoing to create more reliable welds. Wet welding procedures are typically used for subsea maintenance welds while the additional techniques are used mainly for onshore applications.

## 8.6 EMERGENCY REPAIR PROGRAM

The Response to Underwater Pipeline Emergencies (RUPE) was developed on the basis of a study performed by H.O. Mohr and Associates which concluded that:

- 1) mechanical pipeline connectors are the most time responsive and cost efficient method for repairing pipe on an emergency basis;
- 2) diving systems and surface support vessels are generally available and should not be placed on stand-by; and
- 3) the cost for an emergency repair program should be based on a "miles of pipeline" basis per company.

The companies which funded this study then agreed to organize a formal group and participate in an emergency repair program. The RUPE program now has seventeen member companies participating.

The equipment which is stored by RUPE includes Gripper, Inc. repair connectors in sizes 6" through 16"; HydroTech MK IV repair connectors in sizes 20" through 36"; Plidco split sleeve repair clamps in sizes 6", 8", 10", 12" and 16"; and HydroTech split sleeve repair clamps in sizes 20", 24", 26", 30" and 36". The tool inventory is stored in a warehouse in Houston, Texas. The tools and equipment are available to the participating companies 24 hours a day for emergency repairs. Several successful repairs have been completed using this equipment, the largest being 24-inch. In each case the equipment was available as intended. However, deepwater and diverless repairs require additional equipment which must be procured and expedited to the repair site.

The cost per company for this program is based on the percentage of miles of pipe to the total miles of pipe covered by RUPE for a particular pipe size. Members also pay monthly operating expenses for warehousing, managing services, etc.

The RUPE program is managed by H.O. Mohr and Associates. Their duties include storing and maintaining the equipment in such a way that the tools are operable and on-call for emergency use. H.O. Mohr and Associates is also responsible for transferring the necessary components to the repair contractor as needed per emergency repair.

## 8.7

### ANCILLARY REPAIR OPERATIONS

The various pipeline repair methods discussed in this section may require deburial of the pipeline and in some instances the attachment of flanges or similar fittings to the prepared pipe ends. The conventional flanged spoolpiece repair methods require attachment of fittings to each end of the pipeline and, unless hyperbaric welding or cold forging techniques are employed, the pipe end must be retrieved to the surface for the welding operation.

This section of the study examines the ancillary operations required to prepare the pipeline before the actual repair begins and complete the repair so that normal operations may be resumed.

#### 8.7.1

##### Deburial

To enable a pipeline repair operation to take place, a buried pipeline must be uncovered. The length of pipeline requiring deburial is dependent on the type of repair that is to be performed and, therefore, defines the extend of the subsea operations. The installation of a split sleeve only requires approximately 40 feet of deburial, while a hyperbaric weld or mechanical repair can require up 400 feet. The retrieval of a pipe end to the surface for the attachment of a flange or similar piece of equipment requires an extensive length of pipeline deburial on either side of the repair site.

The methods available for uncovering the pipeline over the required length include the use of water jets and dredge pumps. The power is supplied via an electrical umbilical cable from the surface to an electro-hydraulic unit on the seafloor.

The water jet method is based on high pressure water being forced through a small nozzle. The jet is used to fluidize the seafloor material around the pipeline. The equipment is especially suited to clays but it tends to stir up the fine particles which impair the on-bottom visibility.

The dredge pump creates suction at the diver/ROV controlled inlet nozzle. The nozzle is used to suck-up seafloor materials from around the pipeline. The method is especially suitable for sandy seafloor and has the great advantage that it does not impair on-bottom visibility by stirring up fine particles.

## 8.7.2 Pipe Preparation

The repair of submarine pipelines by connector or spoolpiece replacement generally involves two separate operations. First, the damaged pipeline must be prepared to accept the repair device and replacement section. Secondly, the repair device and section must be installed in the line to correct or replace the damaged section.

The amount of pipeline preparation required depends upon the repair situation. In the case of a minor repair, for example, a small local dent is reinforced by installing a pipeline clamp. The extent of preparation may simply involve the removal of a short section of the concrete and corrosion coatings. Where it is necessary to remove a complete pipeline section, the degree of preparation may be extensive, involving replacement of the concrete weight coating and the cathodic protection in the area of damage. Concrete can be removed by several methods such as hydraulic skill saws, hydraulic chippers or high pressure water jets. The hydraulic skill saws are the safest tool and tend to be used in situations where it is critical that the pipe not be damaged. Hydraulic chippers, on the other hand, are used for small areas since the process is slow and tedious. High pressure water jets (10,000 psi and 20,000 psi) are also used but the topside unit requires additional set up time and handling.

Several techniques are available to make the circumferential cut in the submarine pipeline. These include oxy-fuel gas cutting, mechanical cutting and explosive techniques.

In general, mechanical cutters use hydraulic power to drive a steel cutting edge. The cutter moves circumferentially around the pipeline on a crawler track, and is operated by a diver/ROV who adjusts the depth of cut on each complete rotation around the pipeline.

If the pipe end is to be retrieved to the surface, the pipe preparation, apart from the initial cut, will be performed in air. For a mechanical repair or hyperbaric welding the preparation takes place subsea.

## 8.7.3 Dewatering

If, for any reason, it is required that the pipeline requires dewatering in order to facilitate repair of the pipeline or to aid leak detection, then this is achieved by driving a pig by compressed air from one end of the pipeline to the other where the water is discharged at the receiving end.

Alternatively, in the event of a complete rupture of the pipeline it is feasible that the pipeline may be dewatered by barge mounted air compressors which drive pig(s) from each pipeline end to the rupture location. Plugs are fitted to the pipe ends to which air hoses are attached for the dewatering operation.

#### **8.7.4 Pipeline Testing After Repair**

The most reliable way to test a pipeline is with a full hydrostatic test. Although hydrostatic testing can be inconvenient and expensive, it should be undertaken after a major pipeline repair is completed prior to recommissioning. This is particularly important if additional damage is suspected.

In some cases it may be possible to return a pipeline to service without hydrostatic testing. Such a case would be dependent on a combination of circumstances such as:

- the pipeline is new or has been recently hydrostatically tested;
- the damage is known to be small and localized;
- the repair procedure did not disturb a significant portion of the pipeline;
- the repair is fully butt-welded, x-ray and ultrasonically inspected; or
- the normal line operating pressure is significantly lower than the design pressure.

However, the decision not to hydrostatically test the pipeline after a repair should only be considered if the delays incurred would be excessive in terms of loss of revenue. In such cases, the operation of the pipeline would be carefully monitored and the repair inspected by diver/ROV for a sufficient period after the repair operation.

# DATA SHEET

**REFERENCE:** 8.2-1

**AREA:** Intermediate & Major Repair

**CATEGORY:** Established Construction Techniques

**TECHNIQUE:** Hyperbaric Welding

**SUPPLIER:** Comex Services

## KEY PARAMETERS:

- **PIPE DIAMETER:** Up to 36"
- **MAXIMUM WATER DEPTH:** 1000 feet working; 1500 feet max.
- **MODE OF INTERVENTION:** Diver
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive to 700 feet; limited beyond

## ADDITIONAL INFORMATION:

- **Required Equipment:** Welding habitat "Sea Horse"; alignment frames; H-frames; underwater welding module; concrete removal system; jetting equipment; diving spread
- **Vessel Requirements:** 3200 sq. feet deck space; 60 ton crane; electrical and air supplies; station keeping ability
- **Advantages:** Modular components; dry transfer of personnel; stand-by system; extensive lateral transfer ability; equipment can be abandoned on seafloor
- **Disadvantages:** Exact alignment of pipe ends; numerous pieces of equipment

**REFERENCE:** Section 8.2.1

# DATA SHEET

**REFERENCE:** 8.2-2

**AREA:** Intermediate & Major Repair

**CATEGORY:** Established Construction Techniques

**TECHNIQUE:** Hyperbaric Welding

**SUPPLIER:** Global Divers

## KEY PARAMETERS:

- PIPE DIAMETER:
- MAXIMUM WATER DEPTH: 1200 feet
- MODE OF INTERVENTION: Diver
- AVAILABILITY: None
- DEVELOPMENT STATUS: Prototype
- EXPERIENCE: Test

## ADDITIONAL INFORMATION:

- Features: Qualification to 1200 feet for both wet and dry procedures

**REFERENCE:** Section 8.2.1

# DATA SHEET

**REFERENCE:** 8.2-3

**AREA:** Intermediate & Major Repair

**CATEGORY:** Established Construction Techniques

**TECHNIQUE:** Hyperbaric Welding

**SUPPLIER:** Rockwater

## KEY PARAMETERS:

- **PIPE DIAMETER:** Up to 36"
- **MAXIMUM WATER DEPTH:** 1000 feet
- **MODE OF INTERVENTION:** Diver
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive to 700 feet; limited beyond

## ADDITIONAL INFORMATION:

- **Required Equipment:** Welding habitat "CHAS"; pipe handling frame; umbilicals with winches; pipe preparation tools; diving spread; welding spread
- **Vessel Requirements:** Approximately 2000 sq. feet deck space; 200 ton crane; station keeping ability
- **Advantages:** Integrity; ease of inspection; equipment can be abandoned on seafloor; divers are trained to weld (not vise versa)
- **Disadvantages:** Heavy equipment; wet transfer of personnel; derrick barge usually required in addition to support vessel

**REFERENCE:** Section 8.2.1

# DATA SHEET

**REFERENCE:** 8.2-4

**AREA:** Intermediate & Major Repair

**CATEGORY:** Established Construction Techniques

**TECHNIQUE:** Hyperbaric Welding

**SUPPLIER:** SubSea International

## KEY PARAMETERS:

- **PIPE DIAMETER:** 4" to 36"
- **MAXIMUM WATER DEPTH:** 1000 feet
- **MODE OF INTERVENTION:** Diver
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive to 700 feet; limited beyond

## ADDITIONAL INFORMATION:

- **Required Equipment:** Welding habitat and gear; alignment frames or weld ball and socket; pipe preparation tools; diving spread
- **Vessel Requirements:** Deck space; 50 ton crane; station keeping ability
- **Advantages:** High confidence level
- **Disadvantages:** Semi-wet operation
- **Other:** Welding habitats are special built in approximately 10 days; weld ball and socket used where alignment is a problem

**REFERENCE:** Section 8.2.1

# DATA SHEET

**REFERENCE:** 8.2-5

**AREA:** Intermediate & Major Repair

**CATEGORY:** Established Construction Techniques

**TECHNIQUE:** Repair During Pipelay

**DESCRIPTION:** Damage repaired by lay vessel during pipelay

## KEY PARAMETERS:

- **PIPE DIAMETER:** N/A
- **MAXIMUM WATER DEPTH:** Dependent on Vessel and Mode of Intervention
- **MODE OF INTERVENTION:** Vessel/Diver/ROV
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive

## ADDITIONAL INFORMATION:

- **Required Equipment:** ROV; dewatering pig; pipe end cap/pig trap; diving spread
- **Vessel Requirements:** Stinger; tensioners; A & R winch; station keeping ability
- **Other:** Lift capacity limited by A & R winch; applicable for dry and wet buckle damage

**REFERENCE:** Section 8.2.2

# DATA SHEET

**REFERENCE:** 8.2-6

**AREA:** Intermediate & Major Repair

**CATEGORY:** Established Construction Techniques

**TECHNIQUE:** Surface Lift

**DESCRIPTION:** Pipeline is raised by davits or a single point lift to surface for repairs

## KEY PARAMETERS:

- **PIPE DIAMETER:** Dependent on Vessel
- **MAXIMUM WATER DEPTH:** Dependent on Vessel
- **MODE OF INTERVENTION:** Vessel/Diver/ROV
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive

## ADDITIONAL INFORMATION:

- **Variations:** Surface lift with:
  - 1) Surface Weld
  - 2) Surface Swivel
  - 3) Bottom Connect
- **Required Equipment:** Large construction vessel or 2 lift vessels; pipe preparation tools; end caps/spoolpiece/swivel/flexible pipe; welding spread; diving spread
- **Vessel Requirements:** Davits; handling frames; spoolpiece fabrication facility station keeping ability
- **Other:** Buoyancy tanks may be required to decrease pipe weight

**REFERENCE:** Section 8.2.3

# DATA SHEET

**REFERENCE:** 8.2-7

**AREA:** Intermediate & Major Repair

**CATEGORY:** Established Construction Techniques

**TECHNIQUE:** Flanged Spoolpiece Connection

**DESCRIPTION:** Flanged section of damaged pipe is completely replaced by spoolpiece

## KEY PARAMETERS:

- **PIPE DIAMETER:** 4" to 36"
- **MAXIMUM WATER DEPTH:** Dependent on Mode of Intervention
- **MODE OF INTERVENTION:** Vessel/Diver/ROV
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive

## ADDITIONAL INFORMATION:

- **Required Equipment:** Jetting equipment; spreader bar; nut and bolt torquing tools; diving spread
- **Vessel Requirements:** Deck space; crane; welding spread; station keep ability

**REFERENCE:** Section 8.2.4

# DATA SHEET

**REFERENCE:** 8.2-8

**AREA:** Intermediate & Major Repair

**CATEGORY:** Established Construction Techniques

**TECHNIQUE:** Hot Tap and Bypass

**SUPPLIER:** T.D. Williamson

## KEY PARAMETERS:

- **PIPE DIAMETER:** 1/4" to 60"
- **MAXIMUM WATER DEPTH:** Dependent on Mode of Intervention
- **MODE OF INTERVENTION:** Vessel/Diver/ROV
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive to 600 feet; limited beyond

## ADDITIONAL INFORMATION:

- **Required Equipment:** Lock-O-Ring flanged stopple fittings; marinized sandwich valves; tapping machines; stopple plugging machines; bypass line; Lock-O-Ring plugs; blind flanges; spoolpiece; cold cutter tools
- **Vessel Requirements:** Crane; spoolpiece fabrication facility; station keeping ability
- **Max. Operating Pressure:** 1440 psi (2200 psi available)
- **Advantages:** Pipeline does not have to be shutdown or decommissioned; spoolpiece connection can be delayed
- **Disadvantages:** Repair must be used in conjunction with spoolpiece connection

**REFERENCE:** Section 8.2.5

# DATA SHEET

**REFERENCE:** 8.3-1

**AREA:** Intermediate & Major Repair

**CATEGORY:** Proprietary Hardware

**TECHNIQUE:** Flexiforge™ End Connector

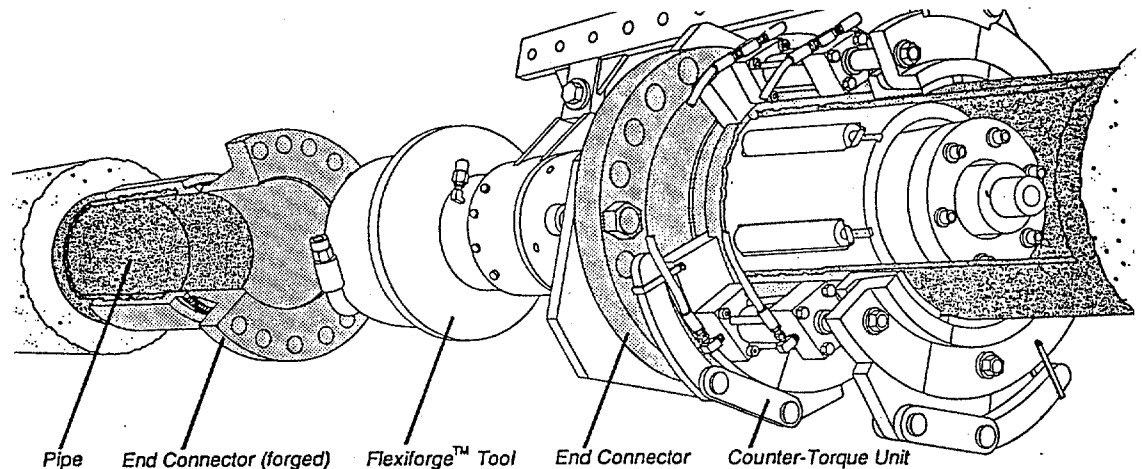
**SUPPLIER:** Big Inch Marine Systems

## KEY PARAMETERS:

- PIPE DIAMETER: 6" to 36"
- MAXIMUM WATER DEPTH: 1000 feet
- MODE OF INTERVENTION: Diver
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Extensive

## ADDITIONAL INFORMATION:

- Connection Method: Hydraulically actuated cold forge
- Seal Type: Metal-to-Metal
- Misalignment:  $\pm 12.5^\circ$
- Ancillary Equipment: Flexiforge™ tool; counter-torque tool
- Other: Minimal pipe preparation; short diver time; high degree of diver skilled required; permanent repair



**REFERENCE:** Section 8.3.2

# DATA SHEET

**REFERENCE:** 8.3-2

**AREA:** Intermediate & Major Repair

**CATEGORY:** Proprietary Hardware

**TECHNIQUE:** Titus (Tie-In Tools for Underwater Systems)

**SUPPLIER:** British Gas/Elf Aquitaine

## KEY PARAMETERS:

- PIPE DIAMETER: 6" to 44"
- MAXIMUM WATER DEPTH: Unknown
- MODE OF INTERVENTION: Vessel
- AVAILABILITY: None
- DEVELOPMENT STATUS: Prototype
- EXPERIENCE: Test

## ADDITIONAL INFORMATION:

- Connection Method: Hydraulically actuated cold forge
- Seal Type: Metal-to-Metal
- Misalignment:  $\pm 3^\circ$
- Ancillary Equipment: Forming tool; Titus system (which incorporates flanges and connectors)
- Other: Minimal pipe preparation; completely diverless; permanent repair; tested to 12,900 psi; connection process lasts 1.5 hours; seal may be tested upon completion

**REFERENCE:** Section 8.3.2

Figure 8.1

# DATA SHEET

REFERENCE: 8.3-3

AREA: Intermediate & Major Repair

CATEGORY: Proprietary Hardware

TECHNIQUE: Camforge™ Repair System

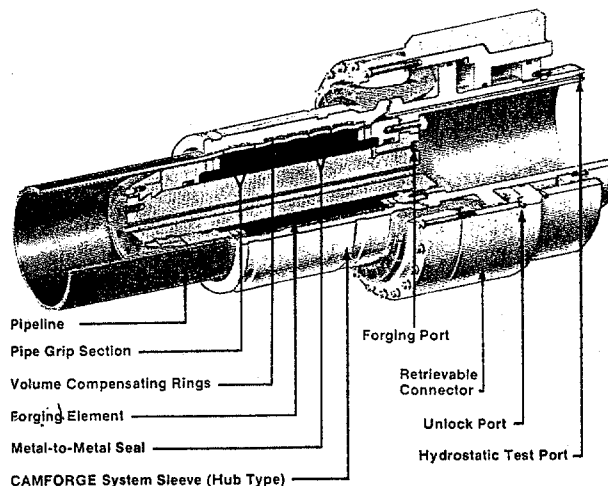
SUPPLIER: Cameron Iron Works, Inc.

## KEY PARAMETERS:

- PIPE DIAMETER: 6" to 36"
- MAXIMUM WATER DEPTH: 1000 feet
- MODE OF INTERVENTION: Diver
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Extensive

## ADDITIONAL INFORMATION:

- Connection Method: Hydraulically actuated cold forge
- Seal Type: Metal-to-Metal
- Misalignment:  $\pm 10^\circ$
- Ancillary Equipment: Tie-in base; running tool; Camforge™ packer
- Other: Minimal pipe preparation; short diver time; high degree of diver skill required; permanent repair



REFERENCE: Section 8.3.2

# DATA SHEET

**REFERENCE:** 8.3-4

**AREA:** Intermediate & Major Repair

**CATEGORY:** Proprietary Hardware

**TECHNIQUE:** Gripper Pipeline Repair System

**SUPPLIER:** Gripper, Inc.

## KEY PARAMETERS:

- **PIPE DIAMETER:** 4" to 30"
- **MAXIMUM WATER DEPTH:** Dependent on Mode of Intervention
- **MODE OF INTERVENTION:** Diver/ROV
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Extensive to 1000 feet; limited beyond

## ADDITIONAL INFORMATION:

- **Components:** Alignment Flange, Ball Connector-Flange Lok, Grip and Seal Mechanical Coupling, Metal Seated Coupling, Grip and Seal Hydraulic Coupling
- **Connection Type:** Nuts and Bolts/Hydraulics
- **Seal Type:** Metal-to-Metal
- **Misalignment:**  $\pm 10^\circ$  ( $\pm 6^\circ$  for pig passage)
- **Ancillary Equipment:** Gripper Snapper Bolt Tensioner
- **Other:** Distinguished service record; requires extended pipe preparation; seals may be tested

**REFERENCE:** Section 8.3.2

Figure 8.2

# DATA SHEET

**REFERENCE:** 8.3-5

**AREA:** Intermediate & Major Repair

**CATEGORY:** Proprietary Hardware

**TECHNIQUE:** Spool Piece Repair Unit

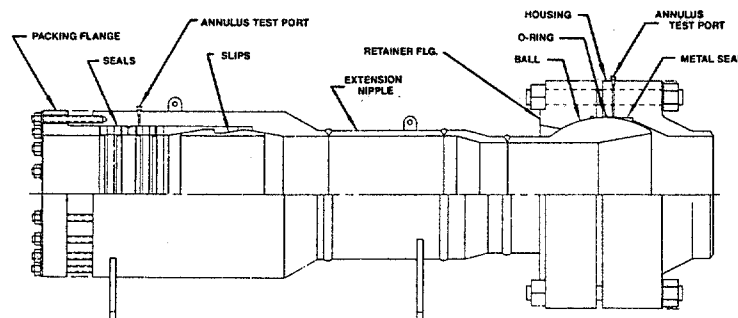
**SUPPLIER:** HydroTech Systems, Inc.

## KEY PARAMETERS:

- PIPE DIAMETER: 3" to 48"
- MAXIMUM WATER DEPTH: 1000 feet
- MODE OF INTERVENTION: Diver
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Extensive

## ADDITIONAL INFORMATION:

- Components: Mark V HydroCouple connector, extension nipple, Misaligning Flange (MAF)
- Connection Type: Nuts and Bolts/Hydraulics
- Seal Type: Elastomeric (Mark V); Metal-to-Metal (MAF)
- Misalignment:  $\pm 12.5^\circ$  ( $6^\circ$  for pig passage)
- Ancillary Equipment: Stud tensioner or hydraulics
- Other: Minimal pipe preparation; separate slips and seals; permanent repair



**REFERENCE:** Section 8.3.2

# DATA SHEET

**REFERENCE:** 8.3-6

**AREA:** Intermediate & Major Repair

**CATEGORY:** Proprietary Hardware

**TECHNIQUE:** Smart Flange Plus

**SUPPLIER:** Oceaneering International

## KEY PARAMETERS:

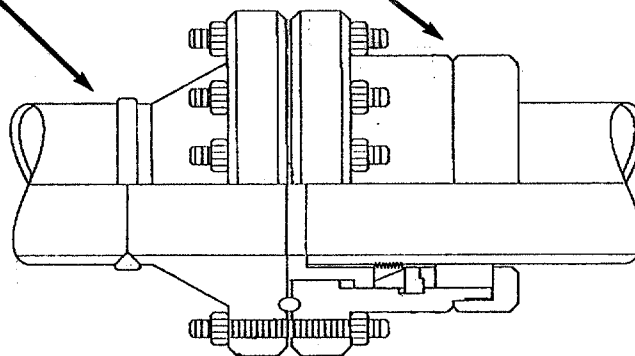
- PIPE DIAMETER: 2" to 24" (larger sizes available)
- MAXIMUM WATER DEPTH: Unknown
- MODE OF INTERVENTION: ROV/Submersible
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Extensive

## ADDITIONAL INFORMATION:

- Connection Method: Nuts and Bolts
- Seal Type: Elastomer
- Misalignment:  $\pm 10^\circ$
- Ancillary Equipment: Torquing Tool
- Other: Smart Flange can compensate for any measurement errors; cannot over-torque nuts; Diverless and Welded Smart Flanges under development

Prefabricated  
Spool-Piece

Smart Flange Plus



**REFERENCE:** Section 8.3.2

# DATA SHEET

REFERENCE: 8.3-7

AREA: Intermediate & Major Repair

CATEGORY: Proprietary Hardware

TECHNIQUE: Split + Sleeve

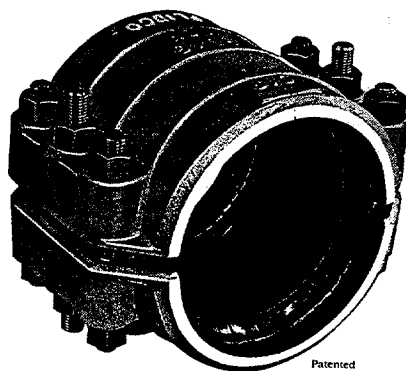
SUPPLIER: Plidco International

## KEY PARAMETERS:

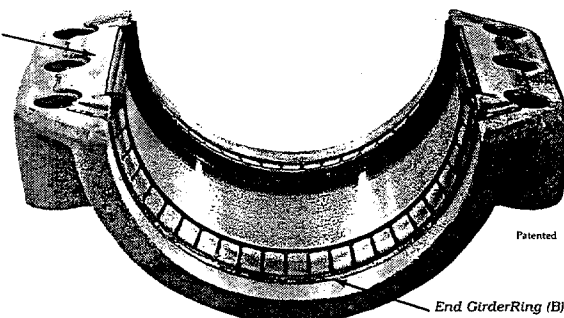
- PIPE DIAMETER: 1.5" to 48"
- MAXIMUM WATER DEPTH: 1000 feet
- MODE OF INTERVENTION: Diver
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Extensive

## ADDITIONAL INFORMATION:

- Connection Method: Nuts and Bolts
- Seal Type: Elastomer/Weld
- Misalignment: 0°
- Ancillary Equipment: Torquing tool
- Other: Available hinged; simple installation; patented GirderRings prevent leaking during installation; pipe must be round



Side GirderRing (A)



REFERENCE: Section 8.3.2

# DATA SHEET

REFERENCE: 8.3-8

AREA: Intermediate & Major Repair

CATEGORY: Proprietary Hardware

TECHNIQUE: Weld + Ends Coupling

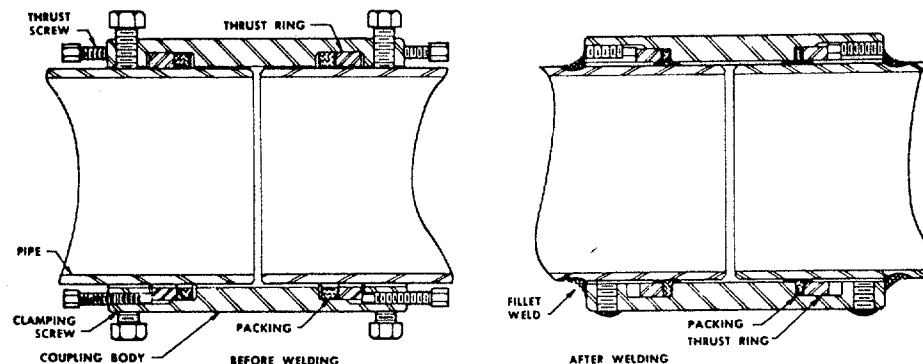
SUPPLIER: Plidco International

## KEY PARAMETERS:

- PIPE DIAMETER: 3" to 52"
- MAXIMUM WATER DEPTH: 1000 feet
- MODE OF INTERVENTION: Diver
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Extensive

## ADDITIONAL INFORMATION:

- Connection Method: Nuts and Bolts
- Seal Type: Metal-to-Metal/Weld
- Misalignment: 0°
- Ancillary Equipment: Torquing tool
- Other: No pipe preparation; good seal integrity; may be permanently welded later, reusable if not; pipe must be round



REFERENCE: Section 8.3.2

# DATA SHEET

**REFERENCE:** 8.3-9

**AREA:** Intermediate & Major Repair

**CATEGORY:** Proprietary Hardware

**TECHNIQUE:** Diverless Clamp Installation Tool

**SUPPLIER:** Stress Engineering

## KEY PARAMETERS:

- PIPE DIAMETER: Unknown
- MAXIMUM WATER DEPTH: Unknown
- MODE OF INTERVENTION: ROV
- AVAILABILITY: None
- DEVELOPMENT STATUS: Concept
- EXPERIENCE: None

## ADDITIONAL INFORMATION:

- Connection Method: Clamp
- Seal Type: Metal-to-Metal
- Misalignment: Unknown
- Ancillary Equipment: None
- Other: Hydraulic power and sensory equipment are only equipment needed other than the specially designed installation tool

**REFERENCE:** Section 8.3.2

# DATA SHEET

**REFERENCE:** 8.3-10

**AREA:** Intermediate & Major Repair

**CATEGORY:** Proprietary Hardware

**TECHNIQUE:** Grayloc® Connector

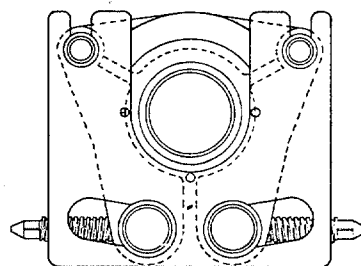
**SUPPLIER:** Vetco Gray

## KEY PARAMETERS:

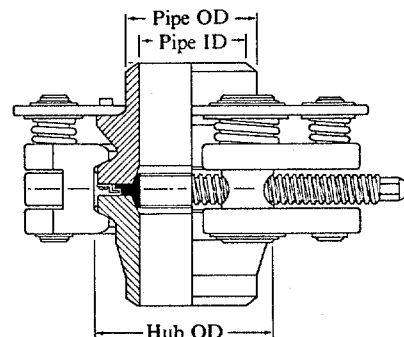
- PIPE DIAMETER: 1/2" to 12", 30"
- MAXIMUM WATER DEPTH: Dependent on Mode of Intervention
- MODE OF INTERVENTION: Diver/ROV
- AVAILABILITY: Worldwide
- DEVELOPMENT STATUS: Operational
- EXPERIENCE: Limited

## ADDITIONAL INFORMATION:

- Connection Method: Clamp
- Seal Type: Metal-to-Metal
- Misalignment: 0°
- Ancillary Equipment: Torquing device
- Other: May be diver operated or remote; internal pressure reinforces the seal; direct substitute for a flange; seals reusable; hubs require welding; permanent repair



Top view



**REFERENCE:** Section 8.3.2

# DATA SHEET

**REFERENCE:** 8.4-1

**AREA:** Intermediate & Major Repair

**CATEGORY:** Integrated Repair Systems

**TECHNIQUE:** SUPRA

**SUPPLIER:** Ferrostaal AG

## KEY PARAMETERS:

- **PIPE DIAMETER:** 12" to 42"
- **MAXIMUM WATER DEPTH:** 1380 feet
- **MODE OF INTERVENTION:** Vessel
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Limited

## ADDITIONAL INFORMATION:

- **Operations:** Pipe alignment; hydraulic supply; hyperbaric or one-atmosphere welding; mechanical coupling connection system; inspection, repair and construction work; core drilling; dredging; pile diving; surface compacting
- **Connection Method:** Varies between welding, hydraulically actuated cold forge, and clamps
- **Seal Type:** Weld/Metal-to-Metal/Elastomeric/Nuts and Bolts
- **Vessel Requirements:** Diving support vessel; diving spread
- **Other:** Can be towed up to 8 knots; remote or manned by 2 divers; 500 feet working radius; detailed information or work area required

**REFERENCE:** Section 8.4.2

# DATA SHEET

**REFERENCE:** 8.4-2

**AREA:** Intermediate & Major Repair

**CATEGORY:** Integrated Repair Systems

**TECHNIQUE:** TRAPR and MARS

**SUPPLIER:** International Submarine Engineering

## KEY PARAMETERS:

- **PIPE DIAMETER:** Unknown
- **MAXIMUM WATER DEPTH:** 3280 feet
- **MODE OF INTERVENTION:** ROV
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Limited

## ADDITIONAL INFORMATION:

- **Operations:** Damage location and assessment; deburial; pipe cutting; section removal; pipe end preparation; pipe alignment; hyperbaric welding
- **Connection Method:** Hyperbaric welding
- **Seal Type:** Weld
- **Vessel Requirements:** Deck space; dynamic positioning; A-frame with auxiliary lifting capacity

**REFERENCE:** Section 8.4.3

Figure 8.3

# DATA SHEET

**REFERENCE:** 8.4-3

**AREA:** Intermediate & Major Repair

**CATEGORY:** Integrated Repair Systems

**TECHNIQUE:** Diverless Deepwater Pipeline Repair System

**SUPPLIER:** Saipem spa

## KEY PARAMETERS:

- PIPE DIAMETER: Unknown
- MAXIMUM WATER DEPTH: Unknown
- MODE OF INTERVENTION: ROV
- AVAILABILITY: None
- DEVELOPMENT STATUS: Prototype
- EXPERIENCE: Test

## ADDITIONAL INFORMATION:

Due to Client restrictions, this information will not be available until Fall 1992.

**REFERENCE:** Section 8.4.4

# DATA SHEET

**REFERENCE:** 8.4-4

**AREA:** Intermediate & Major Repair

**CATEGORY:** Integrated Repair Systems

**TECHNIQUE:** Deepwater Pipe Repair System

**SUPPLIER:** Snamprogetti spa

## KEY PARAMETERS:

- **PIPE DIAMETER:** Unknown
- **MAXIMUM WATER DEPTH:** 3000 feet
- **MODE OF INTERVENTION:** ROV
- **AVAILABILITY:** Unknown
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** Limited

## ADDITIONAL INFORMATION:

- **Operations:** Damage location and assessment; deburial; pipe lifting; pipe cutting; section removal; pipe end preparation; pipe alignment; spoolpiece measurement; cold forging device; spoolpiece fabrication and connection
- **Connection Method:** Hydraulically actuated cold forge
- **Seal Type:** Metal-to-Metal
- **Vessel Requirements:** Deck space; dynamic positioning; crane

**REFERENCE:** Section 8.4.5

# DATA SHEET

**REFERENCE:** 8.4-5

**AREA:** Intermediate & Major Repair

**CATEGORY:** Integrated Repair Systems

**TECHNIQUE:** Challenger AROWS

**SUPPLIER:** Sonsub Services

## KEY PARAMETERS:

- **PIPE DIAMETER:** Unknown
- **MAXIMUM WATER DEPTH:** 3280 feet
- **MODE OF INTERVENTION:** ROV
- **AVAILABILITY:** Worldwide
- **DEVELOPMENT STATUS:** Operational
- **EXPERIENCE:** None

## ADDITIONAL INFORMATION:

- **Operations:** Deburial; pipe lifting; pipe cutting; pipe end preparation; cold forging device; spoolpiece fabrication and installation
- **Connection Method:** Hydraulically actuated cold forge
- **Seal Type:** Metal-to-Metal
- **Vessel Requirements:** Deck space; dynamic positioning; crane

**REFERENCE:** Section 8.4.6

Figure 8.4

METHOD	SUPPLIERS	KEY COMPARISON PARAMETERS						REQUIRED EQUIPMENT	VESSEL REQUIREMENTS	DATA SHEET REF.
		PIPE DIAMETER (IN.)	WATER DEPTH (FEET)	MODE OF INTERVENTION	AVAILABILITY	DEVELOPMENT STATUS	EXPERIENCE			
HYPERBARIC WELDING	• COMEX • SUBSEA • ROCKWATER	UP TO 42	1000 WORKING; 1500 MAX.	DIVER	WORLDWIDE	OPERATIONAL	EXTENSIVE TO 700, LIMITED BEYOND	<ul style="list-style-type: none"> <li>• WELDING HABITAT</li> <li>• ALIGNMENT AND H-FRAMES</li> <li>• PIPE PREPARATION TOOLS</li> <li>• WELDING SPREAD</li> <li>• DIVING SPREAD</li> </ul>	<ul style="list-style-type: none"> <li>• DECK SPACE</li> <li>• CRANE</li> <li>• STATION KEEPING ABILITY</li> </ul>	8.2-1 THRU 8.2-4
REPAIR DURING PIPELAY	PIPELAY CONTRACTOR	CASE BY CASE	DEPENDENT ON VESSEL	VESSEL	WORLDWIDE	OPERATIONAL	EXTENSIVE	<ul style="list-style-type: none"> <li>• INSPECTION ROV</li> <li>• DEWATERING PIG</li> <li>• PIPE END CAP/PIG TRAP</li> <li>• DIVING SPREAD</li> </ul>	<ul style="list-style-type: none"> <li>• STINGER</li> <li>• TENSIONERS</li> <li>• A &amp; R WINCH</li> <li>• STATION KEEPING ABILITY</li> </ul>	8.2-5
SURFACE LIFT	CONSTRUCTION VESSEL OR 2 HEAVY LIFT VESSELS	DEPENDENT ON VESSEL	DEPENDENT ON VESSEL	VESSEL/ DIVER/ROV	WORLDWIDE	OPERATIONAL	EXTENSIVE	<ul style="list-style-type: none"> <li>• WELDING SPREAD</li> <li>• PIPE PREPARATION TOOLS</li> <li>• END CAP/SPOOLPIECE/SWVEL/FLEXIBLE PIPE</li> <li>• DIVING SPREAD</li> </ul>	<ul style="list-style-type: none"> <li>• DAVITS</li> <li>• HANDLING FRAMES</li> <li>• SPOOLPIECE FABRICATION FACILITY</li> <li>• STATION KEEPING ABILITY</li> </ul>	8.2-6
FLANGED SPOOLPIECE CONNECTION	VESSEL CONTRACTOR	4 TO 36	DEPENDENT ON MODE	VESSEL/ DIVER/ROV	WORLDWIDE	OPERATIONAL	EXTENSIVE	<ul style="list-style-type: none"> <li>• JETTING EQUIPMENT</li> <li>• SPREADER BAR</li> <li>• NUT/BOLT TORQUE TOOLS</li> <li>• DIVING SPREAD</li> </ul>	<ul style="list-style-type: none"> <li>• DECK SPACE</li> <li>• CRANE</li> <li>• WELDING SPREAD</li> <li>• STATION KEEPING ABILITY</li> </ul>	8.2-7
HOT TAP AND BYPASS	T.D. WILLIAMSON	1/4 TO 60	DEPENDENT ON MODE	VESSEL/ DIVER/ROV	WORLDWIDE	OPERATIONAL	EXTENSIVE TO 600, LIMITED BEYOND	<ul style="list-style-type: none"> <li>• LOCK-O-RING FLANGED STOPPLE FITTINGS</li> <li>• SANDWICH VALVES</li> <li>• TAPPING MACHINES</li> <li>• STOPPLE PLUGGING MACHINES</li> <li>• BYPASS LINE</li> <li>• LOCK-O-RING PLUGS</li> <li>• BLIND FLANGES</li> <li>• SPOOLPIECE</li> <li>• COLD CUTTER TOOLS</li> </ul>	<ul style="list-style-type: none"> <li>• CRANE</li> <li>• SPOOLPIECE FABRICATION FACILITY</li> <li>• STATION KEEPING ABILITY</li> </ul>	8.2-8

TABLE 8.1

ESTABLISHED CONSTRUCTION TECHNIQUES

METHOD	KEY COMPARISON PARAMETERS						DATA SHEET REF.
	PIPE DIAMETER (IN.)	WATER DEPTH (FEET)	MODE OF INTERVENTION	AVAILABILITY	DEVELOPMENT STATUS	EXPERIENCE	ALLOWABLE MISALIGNMENT
MECHANICAL CONNECTOR	2 - 48	TO 1000	DIVER	WORLDWIDE	OPERATIONAL	EXTENSIVE	± 10°
	0.5 - 30	> 1000	ROV	WORLDWIDE	OPERATIONAL	LIMITED	0° TO ± 10°
	6 - 36	TO 1000	DIVER	WORLDWIDE	OPERATIONAL	EXTENSIVE	± 12.5°
COLD FORGED CONNECTOR	6 - 44	> 1000	ROV	NONE	PROTOTYPE	TEST	± 3°
	0.5 - 52	TO 1000	DIVER	WORLDWIDE	OPERATIONAL	EXTENSIVE	NONE
SPLIT SLEEVE CLAMP	UNKNOWN	> 1000	ROV	NONE	CONCEPT	NONE	NONE

TABLE 8.2  
PROPRIETARY HARDWARE

SYSTEM	SUPPLIER	CONNECTION METHOD	SEAL TYPE	ALLOWED MISALIGNMENT	PIGGABLE	REUSABLE	SEALS TESTABLE	ADDITIONAL DATA AND COMMENTS	DATA SHEET REF.
FLEXIFORGE END CONNECTOR	BIMS	COLD FORGE	METAL-TO-METAL	±12.5°	YES	NO	YES	<ul style="list-style-type: none"> <li>• CONNECTION MADE BY FORGE TOOL AND COUNTER TORQUE TOOL</li> <li>• MINIMAL PIPE END PREPARATION</li> <li>• SHORT DIVER TIME, BUT REQUIRES HIGH SKILL</li> </ul>	8.3-1
TITUS	BRITISH GAS/ELF AQUITAINE	COLD FORGE	METAL-TO-METAL	±3°	YES	NO	YES	<ul style="list-style-type: none"> <li>• CONNECTION MADE BY SPECIAL FORMING TOOL</li> <li>• MINIMAL PIPE END PREPARATION</li> <li>• COMPLETELY DIVERLESS</li> <li>• CONNECTION PROCESS LASTS ONLY 1.5 HOURS</li> </ul>	8.3-2
CAMFORGE REPAIR SYSTEM	CAMERON IPON WORKS	COLD FORGE	METAL-TO-METAL	±10°	YES	NO	YES	<ul style="list-style-type: none"> <li>• CONNECTION MADE BY RUNNING TOOL AND PACKER</li> <li>• MINIMAL PIPE END PREPARATION</li> <li>• SHORT DIVER TIME, BUT REQUIRES HIGH SKILL</li> </ul>	8.3-3
GRIPPER PIPELINE REPAIR SYSTEM	GRIPPER	NUTS & BOLTS/HYDRAULICS	METAL-TO-METAL	±10°	YES	NO	YES	<ul style="list-style-type: none"> <li>• COMPONENTS - ALIGNMENT FLANGE, BALL CONNECTOR FLANGE</li> <li>• LOK, GRIP AND SEAL MECHANICAL COUPLING, METAL SEATED COUPLING, GRIP AND SEAL HYDRAULIC COUPLING</li> <li>• CONNECTION MADE BY BOLT TENSIONER OR HYDRAULICS</li> <li>• EXTENSIVE PIPE END PREPARATION</li> </ul>	8.3-4
SPOOL PIECE REPAIR UNIT	HYDROTECH	NUT & BOLTS/HYDRAULICS	ELASTOMER	±10°	YES	NO	YES	<ul style="list-style-type: none"> <li>• VARIOUS COMPONENTS - MARK V HYDROCOUPLE CONNECTOR, EXTENSION NIPPLE, MISALIGNMENT FLANGE</li> <li>• CONNECTION MADE BY BOLT TENSIONER OR HYDRAULICS</li> <li>• MINIMAL PIPE END PREPARATION</li> </ul>	8.3-5
SMART FLANGE PLUS	OCEANEERING	NUT & BOLTS	ELASTOMER	±10°	YES	UNKNOWN	YES	<ul style="list-style-type: none"> <li>• CONNECTION MADE BY TORQUING TOOL</li> <li>• MINIMAL PIPE END PREPARATION</li> <li>• USES WASP OR ROV</li> <li>• COMPENSATES FOR SPOOLPIECE MEASUREMENT ERRORS</li> </ul>	8.3-6
SPLIT + SLEEVES	PLIDCO	NUTS & BOLTS	ELASTOMER/WELD	NONE	YES	YES	NO	<ul style="list-style-type: none"> <li>• CONNECTION MADE BY TORQUING TOOL</li> <li>• AVAILABLE HINGED</li> <li>• PIPE MUST BE ROUND</li> </ul>	8.3-7
WELD + ENDS COUPLING	PLIDCO	NUTS & BOLTS	METAL-TO-METAL/WELD	NONE	YES	YES, IF NOT WELDED	NO	<ul style="list-style-type: none"> <li>• CONNECTION MADE BY TORQUING TOOL</li> <li>• NO PIPE END PREPARATION</li> <li>• PIPE MUST BE ROUND</li> </ul>	8.3-8
DIVERLESS CLAMP INSTALLATION TOOL	STRESS ENGINEERING	CLAMP	METAL-TO-METAL	UNKNOWN	YES	UNKNOWN	UNKNOWN	<ul style="list-style-type: none"> <li>• HYDRAULIC POWER AND SENSORY EQUIPMENT ARE ONLY EQUIPMENT NEEDED OTHER THAN THE SPECIALLY DESIGNED INSTALLATION TOOL</li> </ul>	8.3-9
GRAYLOC CONNECTOR	VETCO GRAY	CLAMP	METAL-TO-METAL	NONE	YES	YES	YES	<ul style="list-style-type: none"> <li>• CONNECTION MADE BY TORQUING TOOL</li> <li>• MAY BE DIVER ASSISTED OR COMPLETELY REMOTE</li> <li>• INTERNAL PRESSURE OF PIPE REINFORCES SEAL</li> </ul>	8.3-10

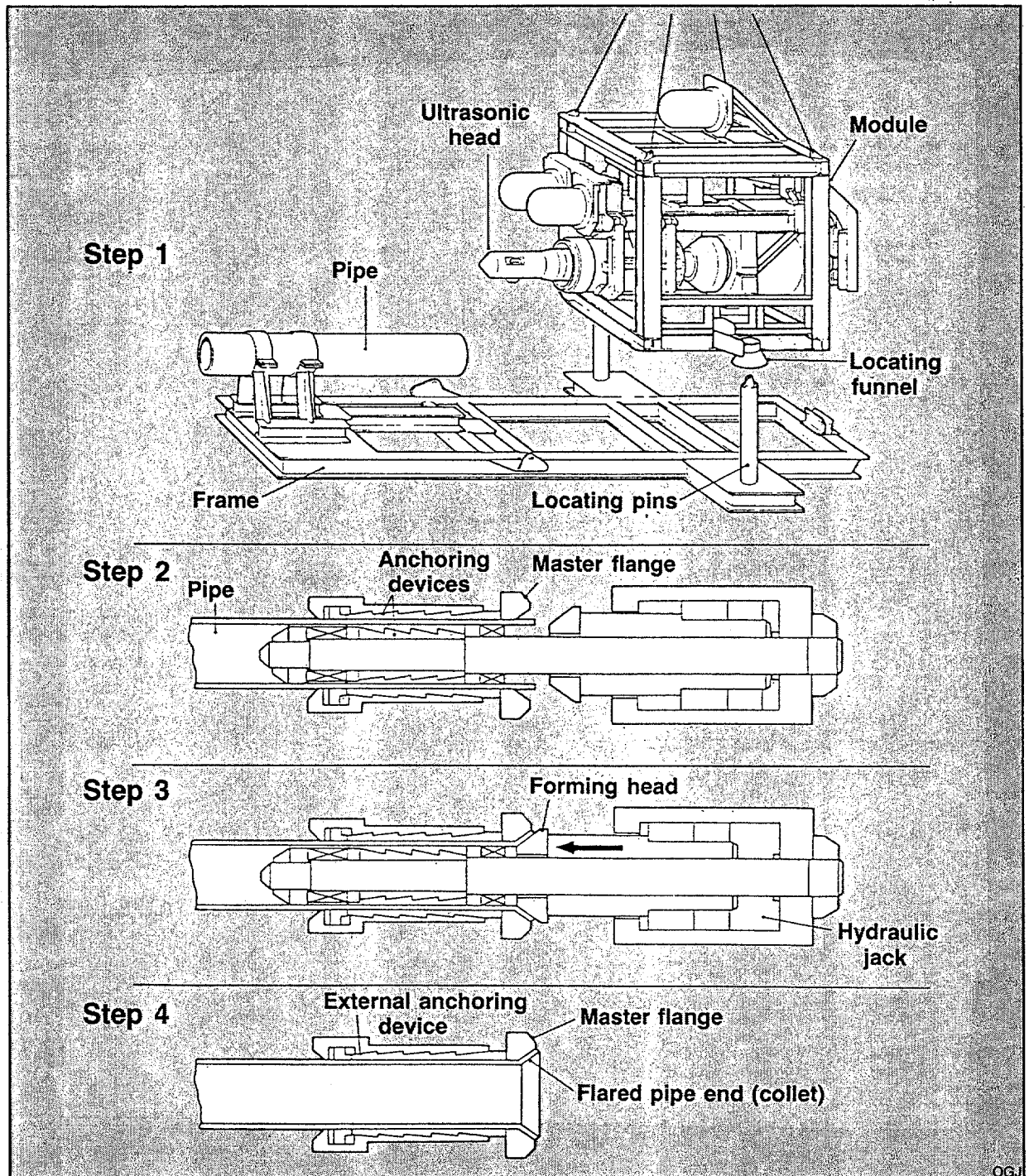
TABLE 8.3  
CONNECTORS

SYSTEM	SUPPLIER	KEY COMPARISON PARAMETERS						ADDITIONAL DATA AND COMMENTS	DATA SHEET REF.
		PIPE DIAMETER (IN.)	WATER DEPTH (FEET)	MODE OF INTERVENTION	AVAILABILITY	DEVELOPMENT STATUS	EXPERIENCE		
SUPRA	FERROSTAAL	12 TO 42	1380	VESSEL	WORLDWIDE	OPERATIONAL	LIMITED	<ul style="list-style-type: none"> <li>• OPERATIONS INCLUDE PIPE ALIGNMENT, HYDRAULIC POWER SUPPLY, HYPERBARIC OR ONE-ATMOSPHERE WELDING, MECHANICAL COUPLING CONNECTION, INSPECTION AND TESTING WORK</li> <li>• LARGE SELF-PROPELLED VESSEL WHICH IS SURFACE TOWED TO SITE THEN DEPLOYED</li> <li>• DETAILED INFORMATION OF WORK SITE REQUIRED</li> </ul>	8.4-1
TRAPR & MARS	ISE	UNKNOWN	3280	ROV	WORLDWIDE	OPERATIONAL	LIMITED	<ul style="list-style-type: none"> <li>• OPERATIONS INCLUDE DAMAGE LOCATION AND ASSESSMENT, DEBURIAL, PIPE CUTTING, SECTION REMOVAL, PIPE END PREPARATION, PIPE ALIGNMENT, HYPERBARIC WELDING</li> <li>• REQUIRES DECK SPACE, DYNAMIC POSITIONING, AND A-FRAME WITH AUXILIARY LIFTING CAPACITY</li> </ul>	8.4-2
DIVERLESS DEEPWATER PIPELINE REPAIR SYSTEM	SAIPEM	UNKNOWN	UNKNOWN	ROV	NONE	PROTOTYPE	TEST	<ul style="list-style-type: none"> <li>• DUE TO CLIENT RESTRICTIONS, DATA WILL NOT BE AVAILABLE UNTIL FALL 1992</li> </ul>	8.4-3
DEEPWATER PIPE REPAIR SYSTEM	SNAMPROGETTI	UNKNOWN	3000	ROV	UNKNOWN	OPERATIONAL	LIMITED	<ul style="list-style-type: none"> <li>• OPERATIONS INCLUDE DAMAGE LOCATION AND ASSESSMENT, DEBURIAL, PIPE LIFTING, SECTION REMOVAL, PIPE END PREPARATION, PIPE ALIGNMENT, SPOOLPIECE MEASUREMENT, COLD FORGING, SPOOLPIECE FABRICATION AND CONNECTION</li> <li>• REQUIRES DECK SPACE, DYNAMIC POSITIONING, AND CRANE</li> </ul>	8.4-4
CHALLENGER ARROWS	SONSUB	UNKNOWN	3280	ROV	WORLDWIDE	OPERATIONAL	NONE	<ul style="list-style-type: none"> <li>• OPERATIONS INCLUDE DEBURIAL, PIPE LIFTING, PIPE CUTTING, PIPE END PREPARATION, COLD FORGING, SPOOLPIECE FABRICATION AND INSTALLATION</li> <li>• REQUIRES DECK SPACE, DYNAMIC POSITIONING, AND CRANE</li> </ul>	8.4-5

TABLE 8.4

INTEGRATED REPAIR SYSTEMS

# PIPE END FLARING PROCEDURE



\*NOTE: THIS PRESENTATION IS TAKEN DIRECTLY FROM "DIVERLESS PIPELINE - REPAIR SYSTEM PASSES TESTS FOR 20 - in. PIPE", OIL AND GAS JOURNAL, MAY 21, 1990.



PROJECT

DEEPWATER PIPELINE  
MAINTENANCE AND  
REPAIR MANUAL

CLIENT:

MINERALS MANAGEMENT SERVICE

TITLE

BRITISH GAS / ELF AQUITAINE  
DIVERLESS PIPELINE REPAIR SYSTEM

SCALE:

NONE

JOB NO.:

2578.01

CAD FILE NO.:

2578001.DWG

DRAWING NO.:

69-3-11-0

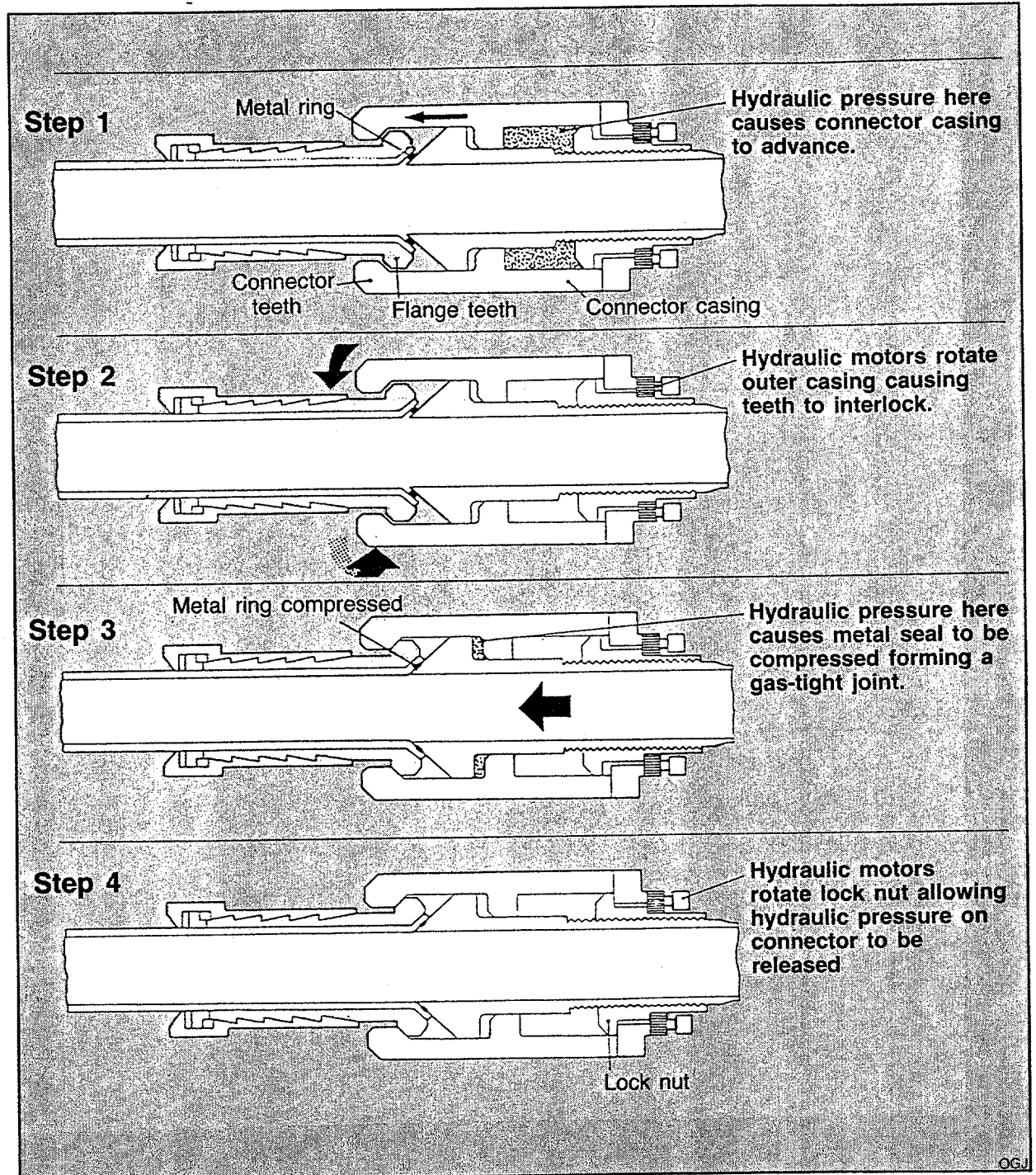
FIGURE NO.

8.1 a

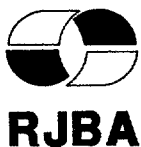
CAD PLT SCALE

1=1

# CONNECTION PROCEDURE



\*NOTE: THIS PRESENTATION IS TAKEN DIRECTLY FROM "DIVERLESS PIPELINE - REPAIR SYSTEM PASSES TESTS FOR 20 - in. PIPE", OIL AND GAS JOURNAL, MAY 21, 1990.



PROJECT

DEEPWATER PIPELINE  
MAINTENANCE AND  
REPAIR MANUAL

CLIENT:

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BRITISH GAS / ELF AQUITAINE  
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SCALE:

NONE

JOB NO.:

2578.01

CAD FILE NO.:

2578001.DWG

DRAWING NO.:

69-3-11-0

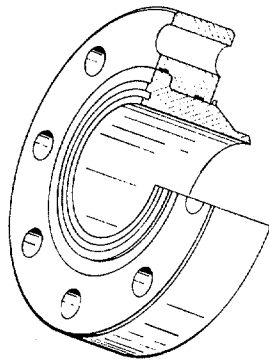
FIGURE NO.

8.1 b

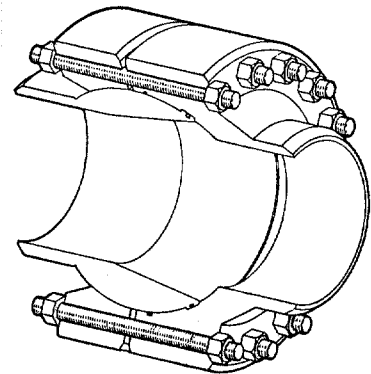
CAD PLT SCAL

1=1

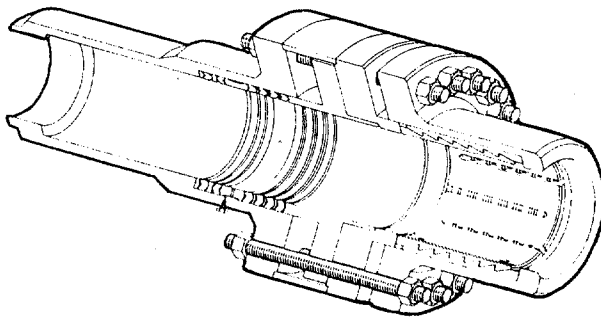
**ALIGNMENT FLANGE**



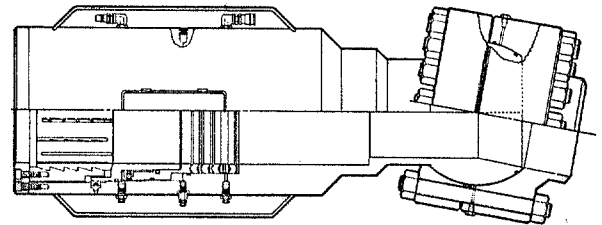
**BALL CONNECTOR FLANGE-LOK**



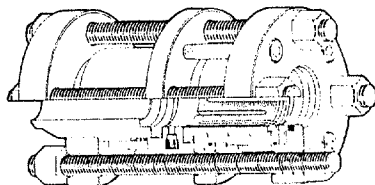
**GRIP-AND-SEAL MECHANICAL COUPLING**



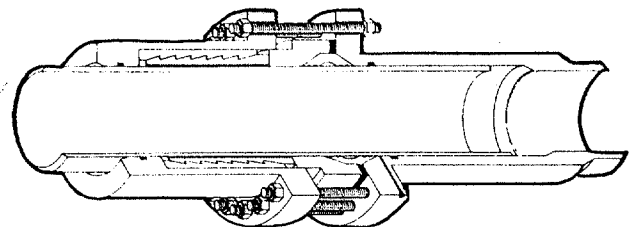
**HYDRAULIC COUPLING**



**METAL-SEATED COUPLING**



**PIPELINE-LENGTH COMPENSATOR**



PROJECT

**DEEPWATER PIPELINE  
MAINTENANCE AND  
REPAIR MANUAL**

CLIENT:

**MINERALS MANAGEMENT SERVICE**

TITLE

**GRIPPER PIPELINE REPAIR SYSTEM**

SCALE:

**NONE**

JOB NO.:

**2578.01**

CAD FILE NO.:

**2578001.DWG**

DRAWING NO.:

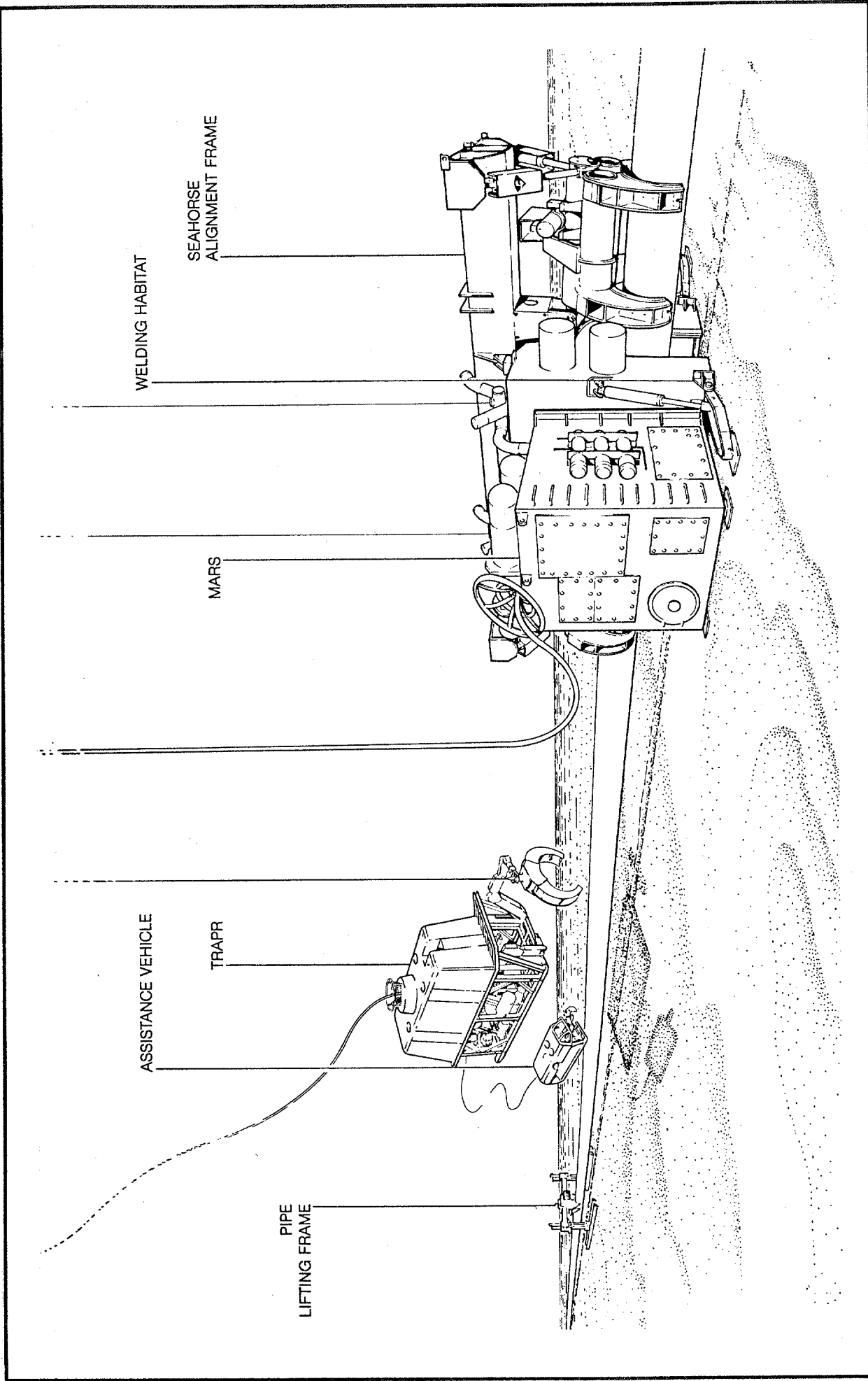
**69-3-11-00**


FIGURE NO.

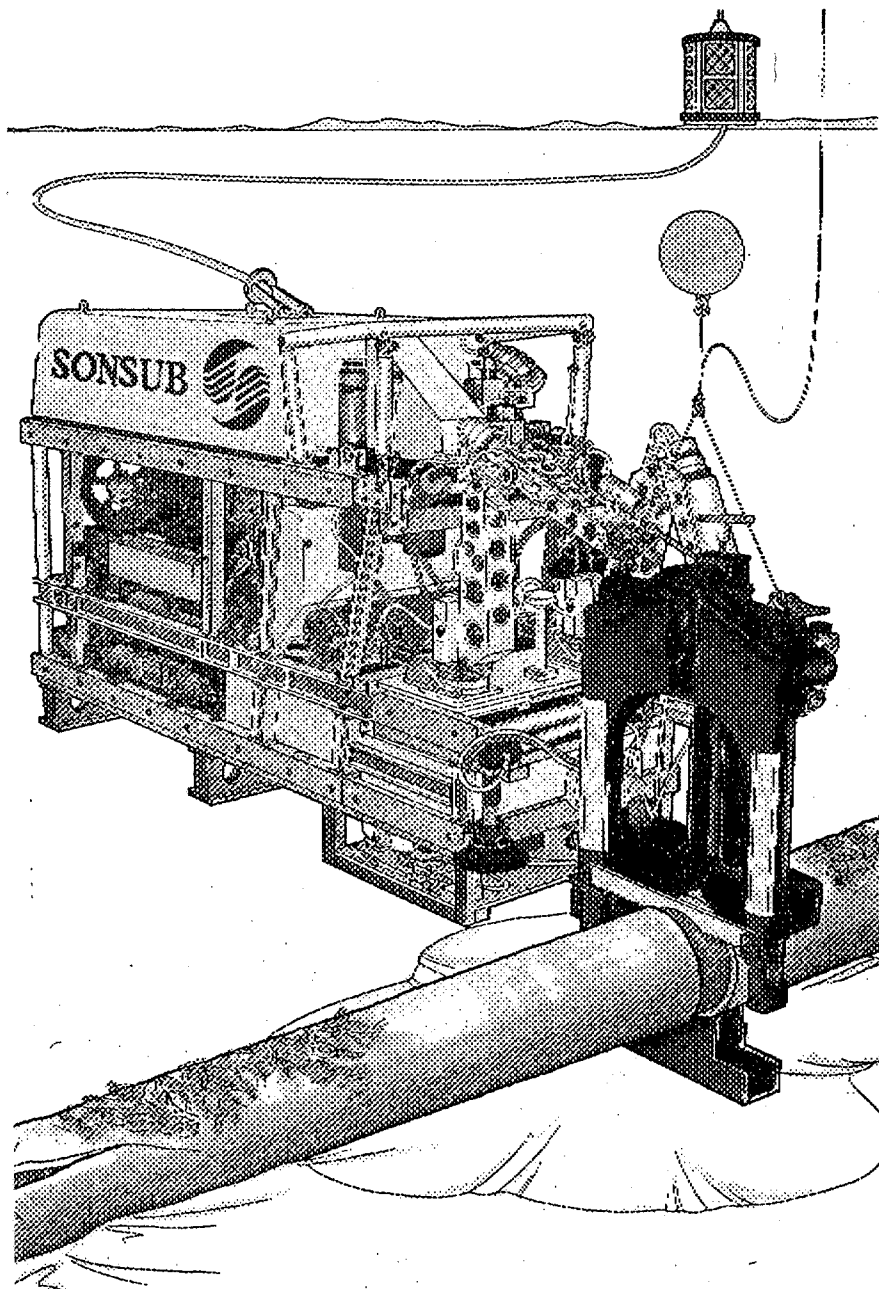
**8.2**

CAD PLT SCALE

**1=1**



 <b>RJBA</b>	<b>PROJECT</b>	<b>DEEPWATER PIPELINE MAINTENANCE AND REPAIR MANUAL</b>	<b>CLIENT</b>	<b>MINERALS MANAGEMENT SERVICE</b>	<b>SCALE:</b> NONE	<b>DRAWING NO.:</b> 69-3-11-001
<b>TITLE</b>	<b>JOB NO.:</b> 2578.01	<b>FIGURE NO.:</b> 8.3	<b>I.S.E. TRAPR AND MARS</b>	<b>CAD FILE NO.:</b> 2578001.DWG	<b>CAD PLT SCALE:</b> 1=1	<b>FIGURE NO.:</b> 8.3



•NOTE: THIS PRESENTATION IS TAKEN DIRECTLY FROM "DEEP WATER PIPELINE INTERVENTION," SEA TECHNOLOGY, APRIL 1992.



PROJECT

DEEPWATER PIPELINE  
MAINTENANCE AND  
REPAIR MANUAL

CLIENT:

MINERALS MANAGEMENT SERVICE

TITLE

SONSUB SERVICES  
CHALLENGER AROWS

SCALE:

NONE

JOB NO.:

2578.01

CAD FILE NO.:

2578001.DWG

DRAWING NO.:

69-3-11-0

FIGURE NO.

8.4

CAD PLT SCALE:

1=1

## APPENDIX

ACOUSTIC SYSTEMS, INC.  
5615 NORTHWEST CENTRAL DR.  
BUILDING C, SUITE 107  
HOUSTON, TX 77092  
TEL: (713) 690-0341  
FAX: (713) 690-0588  
TLX: 880135

BRITISH GAS PLC  
P.O. BOX 3  
GRAMLINGTON  
NORTHUMBERLAND NE23 9EQ  
ENGLAND  
TEL: (44 67) 071-3401  
FAX: (44 67) 073-5893  
TLX: 537945

ADCO INTERNATIONAL LTD.  
MIDDLEFIELD ROAD, MIDDLEFIELD  
INDUSTRIAL ESTATE  
FALKIRK FK2 9HU  
SCOTLAND  
TEL: (44 03) 242-3682  
FAX: (44 03) 243-2570  
TLX: 931213354 AD G

### BUE MARINE DIVISION

TEL: (44 31) 554-9456  
FAX: (44 31) 554-8328  
TLX:

AMERICAN OILFIELD DIVERS  
5599 SAN FELIPE, SUITE 1081  
HOUSTON, TX 77056  
TEL: (713) 462-9080  
FAX: (713) 462-0603  
TLX: 62007660

CAL DIVE INTERNATIONAL  
13430 NORTHWEST FRWY., SUITE 350  
HOUSTON, TX 77040  
TEL: (713) 880-1944  
FAX: (713) 690-2204  
TLX:

BENTHOS, INC.  
49 EDGERTON DR.  
NORTH FALMOUTH, MA 02556-2826  
TEL: (508) 563-1000  
FAX: (508) 563-6444  
TLX: 820673

CAN OCEAN RESOURCES (UK), LTD.  
CANOCEAN HOUSE, 1 FRANCIS GROVE  
WIMBLEDON, LONDON SW19  
ENGLAND  
TEL: (44 81) 946-3910  
FAX: (44 81) 947-5796  
TLX:

BIG INCH MARINE SYSTEMS, INC.  
5650 GUHN RD., SUITE 100  
HOUSTON, TX 77040  
TEL: (713) 460-0003  
FAX: (713) 462-0603  
TLX:

CHAS F. MARTIN & ASSOCIATES  
P.O. BOX 354  
PORTER, TX 77365  
TEL: (713) 354-3342  
FAX: (504) 927-7838  
TLX:

COMEX SERVICES S.A.  
36 BOULEVARD DES OCEANS  
13725 MARSEILLE, CEDEX 9  
FRANCE  
TEL: (33 91) 23 50 00  
FAX: (33 91) 40 12 80  
TLX: 410985 F

GLOBAL DIVERS  
100 ENTERPRISE BLVD.  
HWY. 167 SOUTH  
LAFAYETTE, LA 70506  
TEL: (318) 234-3483  
FAX: (318) 988-5176  
TLX:

COOPER OIL TOOL  
(CAMERON IRON WORKS)  
13013 NORTHWEST FRWY., BOX 1212  
HOUSTON, TX 77251-1212  
TEL: (713) 939-2211  
FAX: (713) 939-2620  
TLX: 775422 CAMIRON HOU

GRIPPER, INC.  
1107 ALDINE MAIL ROUTE  
HOUSTON, TX 77039  
TEL: (713) 449-6205  
FAX: (713) 449-8591  
TLX: 774457

DEEP OCEAN ENGINEERING  
1431 DOOLITTLE DRIVE  
SAN LEANDRO, CA 94577  
TEL: (510) 562-9300  
FAX: (510) 430-8249  
TLX:

H.O. MOHR RESEARCH & ENGINEERING, INC.  
12237 FM 529  
NORTHWOOD INDUSTRIAL PARK WEST  
HOUSTON, TX 77041  
TEL: (713) 466-1527  
FAX: (713) 896-6807  
TLX: 362932

EASTPORT INTERNATIONAL  
13302 REDFISH LANE  
STAFFORD, TX 77477  
TEL: (713) 499-9260  
FAX: (713) 261-4056  
TLX:

HMB SUBWORK LTD.  
BASAEMER WAY, HARFREYS INDUSTRIAL ESTATE  
GREAT YARMOUTH, NORFOLK  
ENGLAND  
TEL: (44 49) 365-0579  
FAX: (44 49) 365-5523  
TLX:

FERROSTAAL AG/DEPT. FN  
P.O. BOX 101265  
D-4300 ESSEN 1  
WEST GERMANY  
TEL: (49 201) 818-2758  
FAX: (49 201) 818-2822  
TLX:

HROS USA CORP.  
3130 ROGERDALE, SUITE 170  
HOUSTON, TX 77042  
TEL: (713) 952-0333  
FAX: (713) 952-1825  
TLX:

HELLE ENGINEERING, INC.  
7939 SILVERTON AVE., SUITE 801  
SAN DIEGO, CA 92126  
TEL: (619) 695-0487  
FAX: (619) 695-3612  
TLX:

INTERNATIONAL PIPELINE PRODUCTS LTD.  
WALKERVILLE INDUSTRIAL ESTATE  
CATTERICK GARRISON  
NORTH YORKSHIRE DL9 4RR  
ENGLAND  
TEL: (44 74) 883-4577  
FAX: (44 74) 883-4121  
TLX: 587819 IPPIC G

HYDRO PRODUCTS  
11803 SORRENTO VALLEY RD.  
SAN DIEGO, CA 92121-1006  
TEL: (619) 453-2345  
FAX: (619) 793-2635  
TLX:

INTERNATIONAL SUBMARINE ENGINEERING, LTD.  
1734 BROADWAY ST.  
PORT COQUITLAM, BRITISH COLUMBIA  
CANADA V3C 2M8  
TEL: (604) 942-5223  
FAX: (604) 942-7577  
TLX:

HYDROBOTICS ENGINEERING CANADA, INC.  
20-520 WESTRAY ROAD SOUTH  
AJAX, ONTARIO  
CANADA L1S 6W6  
TEL: (416) 428-2300  
FAX: (416) 428-3014  
TLX:

INTERNATIONAL UNDERWATER  
CONTRACTOR'S, INC.  
15915 KATHY FREEWAY, SUITE 225  
HOUSTON, TX 77094  
TEL: (713) 579-3474  
FAX: (713) 885-7711  
TLX:

HYDROTECH SYSTEMS, INC.  
11500 NORTHWEST FRWY., SUITE 620  
HOUSTON, TX 77092  
TEL: (713) 688-5277  
FAX: (713) 688-9166  
TLX: 4490506 HYD UI

KLEIN ASSOCIATES, INC.  
KLEIN DRIVE  
SALEM, NH 03079  
TEL: (603) 893-6131  
FAX: (603) 893-8807  
TLX: 947439

INTERNATIONAL HARD SUITS  
1174 WELCH ST.  
NORTH VANCOUVER, BRITISH COLUMBIA  
CANADA V7P 1B2  
TEL: (604) 986-5600  
FAX: (604) 986-7125  
TLX: 4352566

MAIHAK AG  
P.O. BOX 601709  
SEMPERSTRASSE 38  
D-2000 HAMBURG 60  
WEST GERMANY  
TEL: (49 40) 27161  
FAX: (49 40) 271-6242  
TLX: 211158 MHK

MURDOCK ENGINEERING COMPANY  
P.O. BOX 152278  
IRVING, TX 75015  
TEL: (214) 790-1122  
FAX: (214) 313-3289  
TLX: 792996

PERRY TECHNOLOGIES  
275 WEST 10TH ST.  
RIVERIA BEACH, FL 33404-7593  
TEL: (407) 842-5261  
FAX: (407) 842-5303  
TLX: 513439 PERRY RIBH

NKK AMERICA, INC.  
333 CLAY ST., SUITE 3000  
HOUSTON, TX 77002  
TEL: (713) 658-0611  
FAX: (713) 658-0006  
TLX:

PIPETRONIX  
450 MIDWEST RD.  
SCARBOROUGH, ONTARIO  
CANADA M1P 3A9  
TEL: (416) 288-0896  
FAX: (416) 288-9814  
TLX:

OCEANEERING INTERNATIONAL, INC.  
P.O. BOX 218130  
HOUSTON, TX 77218  
TEL: (713) 578-8868  
FAX: (713) 578-5243  
TLX: 775181 OCEANRNG HOU

PLIDCO INTERNATIONAL, INC.  
870 CANTERBURY RD.  
CLEVELAND, OH 44145  
TEL: (216) 871-5700  
FAX: (216) 871-9577  
TLX:

OFFSHORE SYSTEM ENGINEERING, LTD. (OSEL)  
BOUNDARY RD., HARFREYS INDUSTRIAL ESTATE  
GREAT YARMOUTH, NORFOLK NR31 0LY  
ENGLAND  
TEL: (44 49) 365-9916  
FAX: (44 49) 365-3457  
TLX: 975084

ROCKWATER  
333 N. SAM HOUSTON PKWY. EAST, SUITE 395  
HOUSTON, TX 77060  
TEL: (713) 999-3330  
FAX: (713) 999-6363  
TLX:

OTTESTAD BREATHING SYSTEMS (OBS)  
LINDHOLMVEIEN 14  
N-3133 DUKEN  
NORWAY  
TEL: (473) 383-799  
FAX: (473) 385-597  
TLX:

SACHSE ENGINEERING ASSOCIATES, INC.  
5550 OBERLIN DR.  
SAN DIEGO, CA 92121  
TEL: (619) 453-8200  
FAX: (619) 453-7100  
TLX:

SAIPEM S.P.A.  
VIA MARTIRI DE CEFALONIA 67  
20097 SAN DONATO MILANESE (MILANO)  
ITALY  
TEL: (39 02) 520-4094  
FAX: (39 02) 520-23130  
TLX: 310246 ENI SAIPEM

STRESS ENGINEERING SERVICES, INC.  
13800 WESTFAIR EAST DR.  
HOUSTON, TX 77041  
TEL: (713) 955-2900  
FAX: (713) 955-2638  
TLX:

SCANDIVE A.S  
SKAGSTO STRAEN #21  
4029 STAVANGER  
NORWAY  
TEL: (472) 454-6611  
FAX: (472) 454-6181  
TLX:

SUBSEA INTERNATIONAL, INC.  
701 ENGINEERS RD.  
BELLE CHASE, LA 70037  
TEL: (504) 393-7744  
FAX: (504) 392-0351  
TLX:

SEAMARK SYSTEMS, LTD.  
4-5 GOLDEN SQUARE  
ABERDEEN AB1 1RD  
SCOTLAND  
TEL: (44 22) 464-7711  
FAX: (44 22) 464-7917  
TLX: 739976

TDW PIPELINE SURVEYS  
P.O. BOX 1286  
TULSA, OK 74101  
TEL: (918) 582-0311  
FAX: (918) 582-1423  
TLX: 492406

SNAMPROGETTI, S.P.A.  
PIAZZA VANONI 1  
20097 SAN DONATO MILANESE (MILANO)  
ITALY  
TEL: (39 2) 5201  
FAX: (39 2) 520-6226  
TLX: 310246 ENI SNAMPROGE

THYSSEN NORDSEEWERKE GMBH  
AM ZUNGENKAI  
D-2970 EMDEN  
WEST GERMANY  
TEL: (49 21) 850  
FAX: (49 21) 31327  
TLX: 27802

SONSUB SERVICES, INC.  
10905 METRONOME  
HOUSTON, TX 77043-2202  
TEL: (713) 984-9150  
FAX: (713) 984-2109  
TLX: 765081

TUBOSCOPE LINALOG, INC.  
P.O. BOX 808  
HOUSTON, TX 77001  
TEL: (713) 799-5410  
FAX: (713) 799-5406  
TLX: 166563

UNDERWATER ATMOSPHERIC SYSTEMS, INC.  
14210 80TH STREET EAST  
PUYALLUP, WA 98372  
TEL: (206) 848-4046  
FAX: (206) 840-1061  
TLX:

WESTMINSTER OFFSHORE A/S  
TANGEN 12  
BOX 5063 DUSAVIK  
4004 STAVANGER  
NORWAY  
TEL: (472) 441-0621  
FAX: (472) 441-0535  
TLX: 8400156 WEST N

VAN OORD ACZ B.V.  
15 DR. VAN STRATENWEG  
P.O. BOX 458  
4200 AL GORINCHEM  
THE NETHERLANDS  
TEL: (31 18) 304-2200  
FAX: (31 18) 302-8212  
TLX: 25716 ACZ NL

T.D. WILLIAMSON, INC.  
P.O. BOX 3409  
TULSA, OK 74101  
TEL: (918) 446-1941  
FAX: (918) 446-6327  
TLX: 492349

VETCO GARY, INC.  
P.O. BOX 2291  
HOUSTON, TX 77252-2291  
TEL: (713) 466-8853  
FAX: (713) 937-2335  
TLX: 401326 GRAYLOC

VETCO PIPELINE SERVICES, INC.  
1600 BRITTMORE RD.  
HOUSTON, TX 77043  
TEL: (713) 461-6112  
FAX: (713) 461-9236  
TLX: 882265

E.H. WACHS COMPANY  
P.O. BOX A  
WHEELING, IL 60090  
TEL: (708) 537-8800  
FAX: (708) 520-1147  
TLX: